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Ray

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A decorative grey shape is located on the left side of the page, extending from the top to the bottom. It has a vertical, slightly irregular edge on the left and a more complex, curved shape on the right, resembling a stylized architectural element or a modern logo.

Industrial Design Capstone Documentation





Ray

*Smarter Lighting
for Pedestrian Spaces*

*Angela Rose Banner
Jefferson University Capstone Thesis
B.S. Industrial Design 2018*



Thank You

A thesis is a lot of work over a long time - two whole semesters! I would like to thank some of the people who helped keep the momentum on this project going, without whom the final product would be so much less.

First, a huge thanks to the Industrial Design Faculty at PhilaU/Jefferson for directing my idea into a proud example of how I approach the design process.

Another thank you to The Lighting Practice, for a wonderful summer internship that taught me how to think about designing lighting as well as luminaire design. Also for answering my questions over the spring semester, and for letting me come back. I cannot wait to give back what I have learned to such a great company.

I would also like to thank the Philadelphia IES and IALD for providing opportunities to learn from lighting experts from every field, and for coming together to review this thesis, providing critique and validation when it was most needed.

The last group I would like to thank are my friends and family, who have heard so much about this project they could present it themselves. You have inspired me to think about lighting from so many different perspectives. I hope that some of that diversity is represented through the process - it added another dimension each time you taught me something new.



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Preface

This book documents the design process of developing a lighting solution to the complex system that is public pedestrian spaces.

This project grew from an interest in interactive art installations and become a study of how to apply the same technology in a more common object: the city street, as used by people.

Why Pedestrian Spaces?

The technology developed in this project can also be applied to road lighting for vehicles, but the focus is on the pedestrian dominated public spaces. These spaces include (but are not limited to) sidewalks, parks, squares, and plazas. This makes the project about human centered design, not simply meeting code light levels.

The idea of focusing urban design on pedestrian users and not vehicle traffic is a growing movement that has generated some surprising benefits in areas used as case studies. One such movement is the use of super-blocks in Barcelona, which began as a solution for their extreme noise levels and air pollution. The superblocks have helped both those issues, but also boosted neighborhood communities, and improved sales for all of the retail within the blocks.

Lighting for Community

A city is a system that is made up of diverse, overlapping communities. This leads to understanding that the success of public design comes from the strength of the communities that the design facilitates. This makes the ideal public lighting environment one which encourages community users, such as bikers, dog walkers, and joggers, as well as one which draws attention to unwanted users.

Dynamic and Responsive Lighting

Combining the idea of lighting to encourage users in a space with interactive lighting environments lead to the questions that guide the design of Ray: Where is the line between subtle and effective interactive lighting? And what are the extended effects of such a lighting environment?

Ray is not so much a *solution* to the problem of existing public lighting, but rather a demonstration of the potential that human centered, dynamic, and responsive lighting infrastructure can bring to urban design.

Contributors and Consultants

This project could never have happened without real lighting professionals to talk to about it. These are some of the people in the network I built to navigate the opportunities and challenges of the world of lighting infrastructure. They come from all levels and backgrounds of lighting experience, but they have all helped keep my project grounded in the present needs of the lighting world.



Inga Birkenstock

Inga Birkenstock is the principal of Birkenstock Lighting Design in San Francisco. She has 30 years experience in architectural lighting and interior design. I consulted with Inga on what features and appearances make a fixture appealing to lighting specifiers. Her recommended fixture became my starting point for research on the styles of pedestrian fixtures available and desired.



Jared Widmer

Jared is a Principal at TLP and the former IES President for the Philadelphia region. He is incredibly busy but always finds the time to be interested in this project when I want to ask for advice. He pointed my research towards the Osram Omnipoint as an example of an interior light with a similar effect. He also explained that the interior fixture was not getting far because of interior energy code, but that the concept applied to an exterior fixture could work because of the higher energy budgets.



Lillian Knoerzer

Lilly is the IALD (International Association of Lighting Designers) Regional Coordinator. She is organized the IES and IALD critique of the lighting Capstone projects when I asked if I could get a panel of experts to review my work. Lilly is also a lighting designer and project manager at TLP, with experience as a manufacturer representative and a background in interior design.



Rochelle Spahn

Rochelle is an associate at TLP, who also is an adjunct professor at Drexel University. She was very patient when I would ask questions about lighting design and fixture criteria, especially the advantages of direct vs indirect light sources.



Chelsae (Benewicz) Bauknecht

Chelsae is the other IALD Regional Coordinator. She is also an interior design professor at PhileU/Jefferson. She has been very enthusiastic about collaborating and sharing resources with the Industrial design students who want to learn more about lighting from the architectural side. I learned about the existing lighting control options that are available from one of her classes I was invited to attend.



Alex Marino

Alex is an ID classmate of mine who has much more experience with electronics. He has saved my prototypes from exploding looked and my buggy arduino code so many times, this project would not have have a single working LED diode without his advice and help.

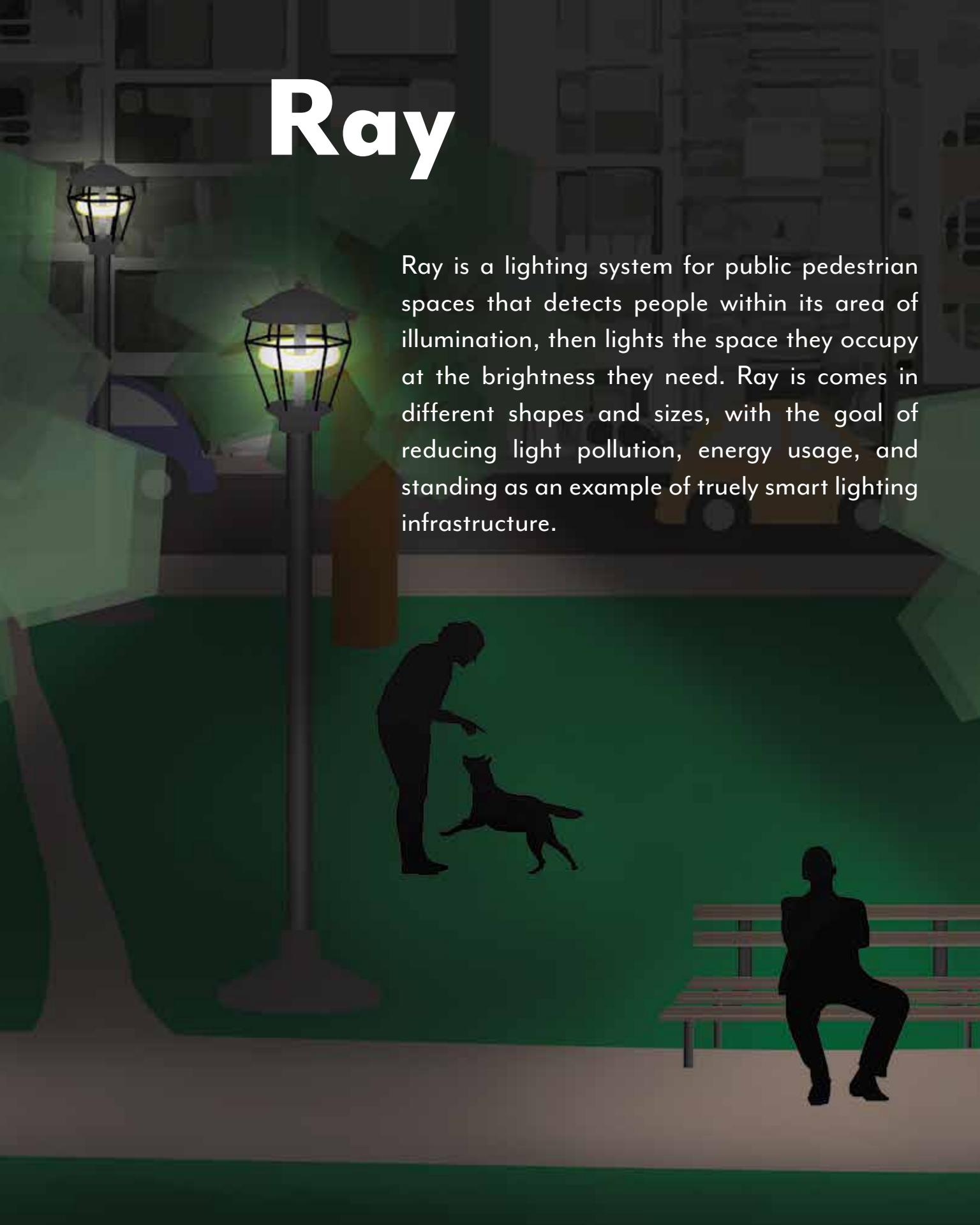


Lyn Godley

Lyn is the lighting professor of the Industrial Design program. She is a product designer, and does art-light shows and installations. Lyn has always been able to put the project into perspective based on what is already out there, and is always pushing the make the next breakthrough in lighting.

Ray

Ray is a lighting system for public pedestrian spaces that detects people within its area of illumination, then lights the space they occupy at the brightness they need. Ray is comes in different shapes and sizes, with the goal of reducing light pollution, energy usage, and standing as an example of truly smart lighting infrastructure.



Smart lighting for pedestrian spaces



Background

Why do we have public lighting?

You can't get more than a paragraph into any research on lighting without the word safety coming up. All municipal lighting is for safety at night. Safety includes car accidents, tripping on uneven ground, and deterring robberies.

Everyone is invested in public lighting, but some people pay for it, other use it, and others want it. Balancing the needs of these interest groups is a key part of designing Ray.



Empty street with public lighting



London lamplighter 1930

With all this discussion of urban communities and interactive lighting, it is important to establish the purpose of public lighting.

Why We Have Public Lighting

The lighting of public spaces has been a responsibility exerted by municipal powers for centuries.

The first modern case of public lighting was a law passed by the Mayor of London in 1417 requiring all homeowners to hang a lantern outside their front door to illuminate the street. This made the private citizens responsible for contributing to the illumination of public spaces, and the citizens' responsibility is enforced by the municipality. Similar laws went into effect in other cities over the next few centuries, gradually shifting the burden of illumination onto the city, who employed lamplighters to maintain the candle-powered luminaires.

In 1617, the city of Paris began the tradition of ringing a large bell once all the lamps in the city were lit. The bell served as an announcement that **the streets were now safe** - the first recorded direct connection between lighting and safety.

In Paris and in other cities, the idea of safe, illuminated streets was met with controversy. This is because the “safety” the lighting provided was for the wealthy upper class, not everyone. The criminal and lower classes of that time had made the streets their own territory once the sun went down. They knew their neighborhoods well enough to navigate without the new lighting, and could go about their private business under the cover of darkness. Some of the wealthy resented the lighting as well, because it made them recognizable when they wanted to do questionable business at night.

This demonstrates the core of why it is important to light public spaces:

Well illuminated spaces allow the people there to be observed.

With the possibility of observation comes “appropriate” behavior.

Looked at the other way, individuals with activities they do not want observed must seek out areas that are without other people, and/or very dark.

Safety is a Public Service

Based on the above, there are two general criteria for creating safety:

1. **Multiple people in the location**
2. **Doing things that can be seen by each other.**

We need light to see (other people) at night, thus safety and lighting become tightly interlinked.

However, lighting alone cannot produce safety.
Safety requires other people.



***What makes
an area safe?***

Security lighting is about the reduction and prevention of crime.

The data on crime rates and light levels in urban areas is pretty easy to find, but it does not prove that making dangerous areas brighter reduces crime.

The most dangerous neighborhood in Chicago is lit at up to 30fc, and the increased illumination has not reduced the crime rate at all. Case studies of lighting and crime are highly contrary and do not show clear correlation and certainly not causation.

Blacking out an area will not stop crime.
Bright security lighting will not stop crime.

Some studies suggest that appropriate lighting can deter opportunistic crime:

- **It cannot be pitch black**, or there is no way to tell if crime is occurring.
- **It cannot be too bright**, or victims are loose their night vision, and become easy targets.

And none of this matters if no person is available to witness and call the cops on any crime that may or may not be occurring.

Lighting for Security Lighting for Safety


“Safety is an experience, not a number.”

Therefore, safety can only be studied through individuals reactions to an experience. This qualitative data is very subjective, and heavily influenced by personal experience.

Lighting can make an area *feel safer*, which can include lighting that will prevent tripping on a pile of leaves, or make pedestrians visible to cars.

We get our sense of safety from a combination of factors, including:

- Line of sight (Are you visible to others?)
- Previous experience (familiarity with area)
- Other people (herd immunity)



If a crime occurs in a brightly lit parking lot, but there is no one there to see it, is the parking lot still dangerous?

“It’s never really desolate,” she said.
“Every 100 feet I see runners and other dog walkers.”

-Dianne Montague, night dog walker in Central Park

Benchmark 1

**The fixture must provide a
safe experience**

Stakeholders in Public Lighting

Who needs it most, who uses it most,
and who pays for it?



Residential townhouses

Now that it is established that public pedestrian lighting is needed, it is time to discuss who the lighting really benefits.

“Public” lighting is for everybody- or it should be, at any rate. But because this project is focused on lighting public pedestrian spaces, there are some groups of more specific stakeholders.

Residents

The people who live in the areas overlooking public spaces. They may rent or own, but all of them care if what’s outside of their windows is safe, distracting, or dangerous. Residents also have the most to worry about light pollution - if the areas outside their homes are too bright, it can affect their sleep.

Retail

Shops, restaurants, and other local small businesses depend on their location for foot traffic. More people walking by equals more sales. Retail, especially small local retail, wants public lighting that attracts people to their street and makes it safe enough for them to stay.



Retail with busy sidewalk at night



Mr. Blumberg exercises at night in Central Park, NYC

Residents and Retail are the groups that are the most invested in the quality of the lighting in their area, but they are not always the groups actually using the public areas as the sun goes down.

Leisure Groups

The groups that actually use these public spaces after dark are often residents, but also just people passing through. Dog walkers, runners, and commuters all use pedestrian spaces like sidewalks, parks, and squares at later hours. This is because these are activities that occur outside of working hours. Most people work during the daylight hours, which pushes their other activities into the time before or after work, often when the sun is going down or not up at all. These are also the people that make up much of the foot traffic that businesses need to attract. Because these groups use the

public spaces deliberately, they choose where to be, and where not to be. This decision is based on a lot of factors, but often on how the areas “feel.” These groups want to use public areas that feel pleasant and safe - both feelings that appropriate lighting can generate.

Local Authorities

The municipality that governs these public spaces is also the decision maker on how they are

illuminated. They pay for the installation, maintenance, and electricity for public lighting. They enforce regulations about what level of illumination is appropriate for each area, and set times for these spaces to be open and closed. Most of this regulation is done for safety, with saving money a close second.

Lighting for Community

Together all of these groups form a single interwoven community around a public pedestrian space, whether it is a sidewalk or park. Stronger communities share these spaces and use them throughout the day. **Lighting can be a powerful tool toward making these community space usable, pleasant, and safe at night.**



Street lighting in London

Benchmark 2

**The system must address
the main concerns of each
stakeholder group:**

- Energy cost**
- Nuisance**
- Safety**

Existing Products

Designing an intelligent light fixture requires 3 main pieces:

1. A Luminaire or fixture. This is the body of the product.
2. The light source or lamp. This produces the illumination.
3. Intelligence. This is the system of sensors and controls that let the light respond to its environment.

Also included are examples of proposed smart street lighting concepts and some existing responsive lighting installations.

Outdoor Lights 101



Pole-Mounted
Area Light

This is the most common fixture in pedestrian spaces. It goes by many names, but it is always a light at the top of a pole. Multiple lamps can be mounted on top of a single pole for greater illumination.



Cantilevered
Pole or
"Cobrahead"

These fixtures are design for wide roads with cars. They extend over the road to get more light on the driving surface, and less on the sides. They can be very tall to cover more road with a single fixture. They are for cars, not people.



Compound
Pole

The compound pole is a road-lighting fixture on the same pole as a pedestrian area light. Typically seen in areas with a lot of pedestrians on sidewalks and lots of traffic on the roads.

Common categories of fixture and function



Wall Mounted

The outdoor version of a sconce, wall mounted fixtures are intended for pedestrian spaces near buildings. They can replace poles along paths that run along the edge of a building, and draw attention to entrances.



Bollard

Miniature poles for people-scaled spaces. These fixtures are no more than 4 feet tall and light the ground where people walk. Short fixtures require tighter spacing, and thus more fixtures.



In-Ground
Recessed

These lights have one limitation: they can only illuminate up from a surface instead of down onto a surface. Ground lights are used to uplight other objects in a pedestrian space like trees or walls. Looking down into them is a great way to get a face full of glare.

Lamp types used in area fixtures

The lamp is the device that emits the light in a luminaire. The lamping used will determine the energy efficiency, lifespan, brightness, light quality, and controls of a fixture. These are the most common lamps in area lighting, and I have rated each. The “best” lamp is the one that has the lowest energy cost and maintenance, but the highest quality light and controls. This makes LED the clear winner.



Incandescent

The oldest electric lighting. Runs electricity through a tungsten filament, which resists the energy and releases heat and light. These lamps need to be replaced regularly and use a lot of power.

Energy Cost

Maintenance

Controls

Light Quality



Metal Halide (HPMV)

High Pressure Mercury Vapor lights produce a very bright white light, but use a lot of energy. They are most used for large highways and security in parking lots.

Energy Cost

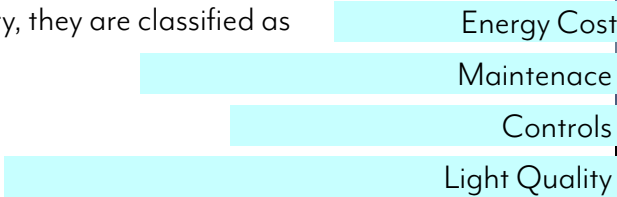
Maintenance

Controls

Light Quality

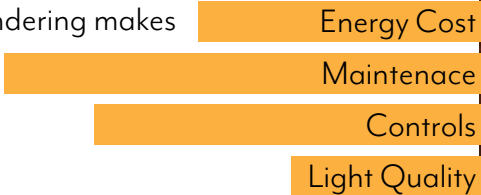
Florescent

An electric current in the gas excites mercury vapor, which produces short-wave ultraviolet light that then causes a phosphor coating on the inside of the lamp to glow. The typical luminous efficacy of fluorescent lighting systems is 50–100 lumens per watt. Because they contain murcury, they are classified as hazardous waste.



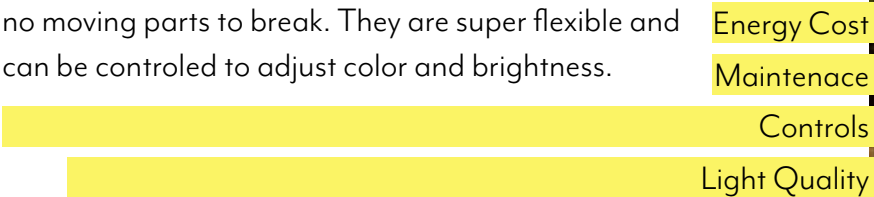
Sodium Vapor

The orange street light that lights a crime scene and you cannot tell whether that puddle is water, oil, or blood. This lamp turns any scen into a black and white nior film, with negative color rendering. It was very cost effective when it was invented, and got put everywhere. The poor color rendering makes it a safety hazard, as well as the occational explosion.

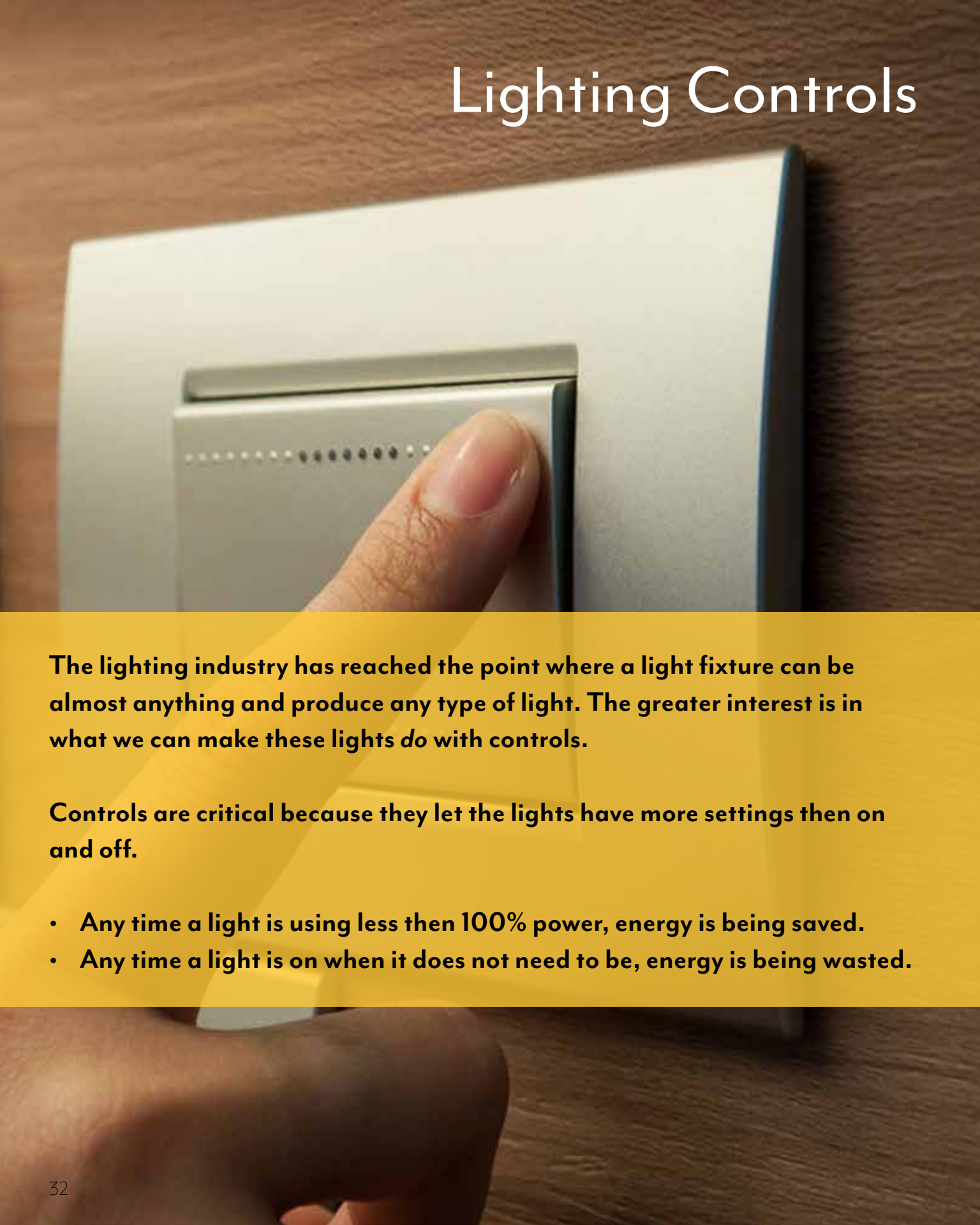


LED

Light Emitting Diodes are the present and future of all lighting. The lamp is a chemically coated chip that emits light when a current is passed through in the correct dirrection. These lamps are rated for 50,000 hours minimum, and as solid state lighting they have no moving parts to break. They are super flexible and can be controled to adjust color and brightness.



Lighting Controls

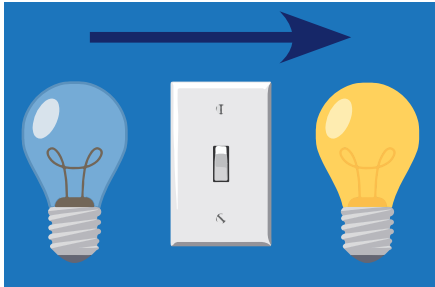


The lighting industry has reached the point where a light fixture can be almost anything and produce any type of light. The greater interest is in what we can make these lights *do* with controls.

Controls are critical because they let the lights have more settings than on and off.

- **Any time a light is using less than 100% power, energy is being saved.**
- **Any time a light is on when it does not need to be, energy is being wasted.**

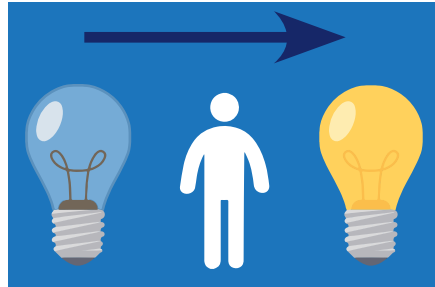
On, off and everything in between



Manual Controls

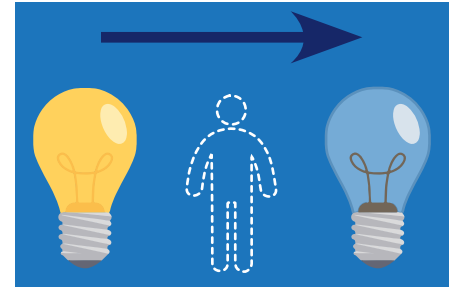
This is a switch that people have access to. It can be **on or off**. In public lighting, this means the lights are all wired back to a control panel that a municipal official can access.

This is used as an override rather than intelligence.



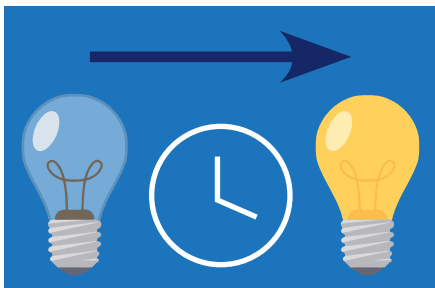
Occupancy

A light controlled by an occupancy sensor defaults to off. These are controls are linked to occupancy sensors. Occupancy sensors use infrared beams or microphonics to detect the **presence of people**. When there is a person, the light is turned on.



Vacancy

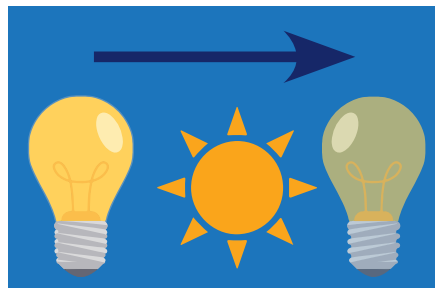
A light controlled by a vacancy sensor defaults to being on. These controls use infrared and microphonic sensors to determine if the space is empty. When the sensors register the **absence of people**, and the light turns off.



Scheduling

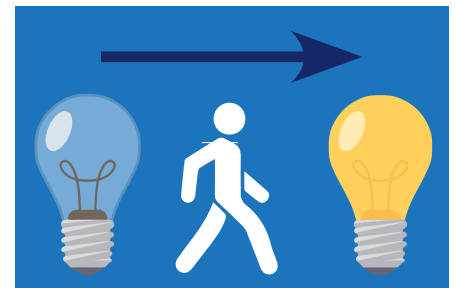
This is a **timer for the lights**. On, off, and dimming can all be set up and run on a 24 hour cycle.

An even smarter way of using scheduled controls for public lighting is to use a digital clock that can account for the time the sun sets and rises.



Daylight Harvesting

Lights controlled with daylight harvesting **respond to the level of light already in a space**. They use a photosensor to measure the illuminance on surfaces in the area. If the area is too bright, the controller will **dim the output of the light**.



Motion Activated

These controls use infrared beams to detect motion in an area. You may have them as a security light or porch light. The amount of motion required to set them off can be an issue - resolved by adding a low resolution **camera to detect the size of the motion**.

Benchmark 3

**Use energy saving LED
lights and automatic
digital controls**

Smart Lighting Examples

Sensors, controls and communication technology in your streetlights have the potential to create a grid of Internet of Things devices throughout your town. Each light pole becomes an intelligent brain cell in your smart city.

The idea of intelligent infrastructure network beginning with lighting is not new. Several companies are developing master network control systems that promise a variety of features, including:

- **Energy efficient LED lighting** system reduces carbon footprint and long term operation costs
- Operational integration with real time **data allows lighting control** as and when required
- Street disturbances and law and order system monitoring through **noise detection**, CCTV and community response
- **Traffic flow monitoring** and data generation for city planning
- **Air pollution monitoring** integrated into the lighting network
- Extension of **WiFi** services through the street light network.

IntelliStreets Smart Light Concept

This concept has a couple of issues:

1. Privacy. These features turn each post into a passive informant on pedestrians in its area.
2. Attaching extra stuff to the fixture makes the pole more intelligent, but not the actual lighting.
3. This design is mostly geared toward collecting data on vehicles for traffic flow, noise, and air quality.

This type of fixture is gaining popularity in cities with a lot of crime and gang activity, such as Los Angeles and parts of Chicago. In those cases, enhancing the police function is more important than privacy to the municipality. Although the law abiding citizens who are also being monitored are not happy.

Existing products are not focused on the *individual experience* that smart lighting can provide.

Wireless Dual Band
Mesh Transceiver



App Based
Wireless Control



RGBA Notification
(indicator light)



Concealed Placement
Speaker (CPS)™



- Music
- Announcements
- Alerts

Image Sensor *



- Proximity sensors
- Pedestrian counter

MAIN ST

Digital street sign *



Façade lighting *
(Color Changing)



Digital Signage *

- Way finding
- Traffic direction
- Alert notification
- Civic information
- Revenue generation via advertising

Environmental
CBRNE Sensors *
Seismic Sensors



Water Detection *



Push to Talk system
"Blue emergency light" *



* Optional Features



Styles from traditional to
contemporary available

Lighting for Experience

Interactive art installations are designed to light spaces and people to give an experience. The common experience was to light where the people are in the space.

Studio Roosegard Van Gogh Path (right). This lighting installation uses solar charging chips that are embedded in the pavement of the path to provide illumination for bikers at night. This is effective and beautiful lighting because it clearly defines the space for the bikers to use. It creates a beautiful experience of walking on swirling galaxies, and it uses no power because the chips are solar charging.

Studio Roosegarde Gates of Light (bottom) This is a lighting installation that uses no power. The designs on the floodgates are created from a super prismatic reflective material that reflects the light from car headlights as they drive across the bridge. This is interactive because the gate illuminates with the passage of people across the bridge, and darkens when they leave.

This is less ideal for pedestrian areas, because people do not have headlights on them all the time. Still, a very elegant way to use an existing light source and generate a dynamic, immersive experience.





Studio Roosegarde Dune (top). This installation is a great example of interactive lighting. Each light reed has sound an motion sensors that cause it to light up when people are near. This playful effect is personal, magical, and very clever. Keeping most the the reeds off until a person walks by saves power, and lets the areas with people stand out against the darkened, empty stretches.

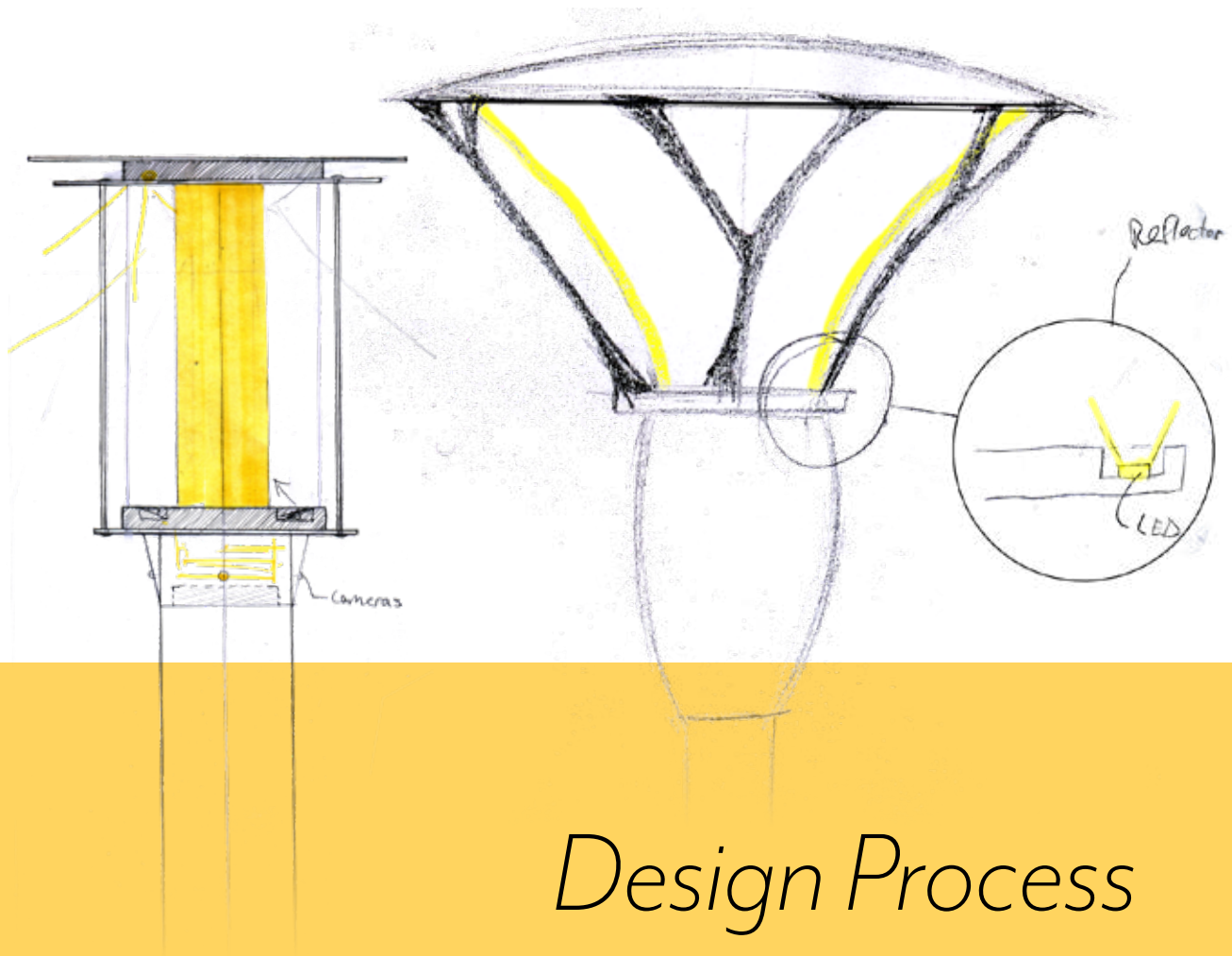


There is a clear difference between these installations and a street light- they are works of art, and a street light is utilitarian. However, these installations save power, make these spaces safer, and draw people to them - all things desirable in any public space. Why can't an everyday lamppost provide a similar interactive experience?

Light the space where the people are

Benchmark 4

**Provide interactive lighting
environment that places
light at peoples' location**



Design Process





Initial Concept

Light pole with directional control

Moving forward with lighting for pedestrian spaces, I began by studying how people actually use these public areas. I identified key activities and how the lighting should be for each activity. These activities were:

- Transit - people in pedestrian spaces that are just passing through. Commuters, joggers, and errand runners are all just going from one point to another and passing through the public space on the way.
- Relaxation - people relaxing in pedestrian spaces are not moving around much and stay in the same area for more than a minute. These are the people who use the benches, chairs, and sometimes bring blankets to sit on.

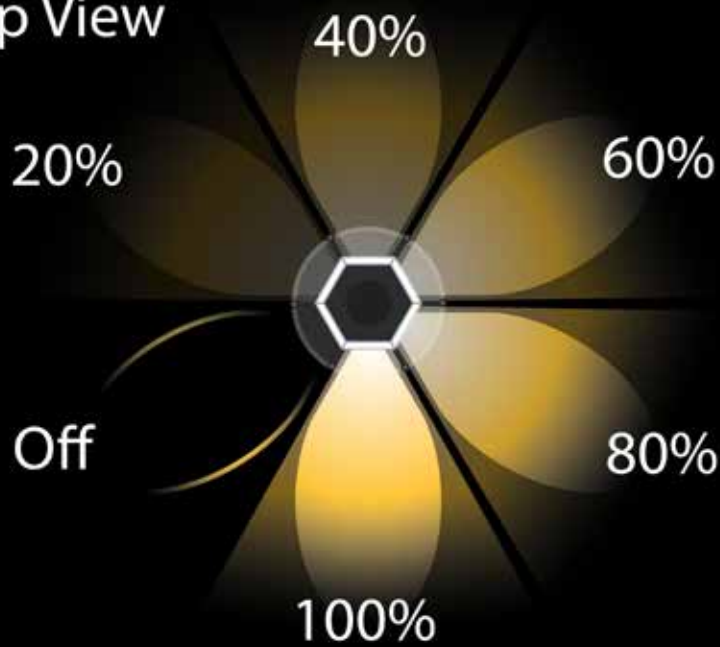
- Socializing - Groups of people use pedestrian spaces as gathering points to get together. The goal of these groups can be transit or relaxation, but because more people make more movement and take up more area, the lighting needs to change to account for groups.

The best lighting for each activity is slightly different. People in transit want light on the ground and ahead of them. People relaxing want to feel safe and observe their surroundings. The social people want light on faces and in a larger zone around them.



Key pedestrian activities and how each should be illuminated.

Top View



My first concept to address the different users of pedestrian spaces was a light pole or post top luminaire. The light would come from different panels to shine in six directions all around and two types of lens for further lighting targets, and closer lighting targets. This made for a total of 12 “beams” coming from one luminaire that could be controlled independently.

That control would need to be based on something though: people in the space. This concept used a combination of microphonics (tiny microphones that detect people sounds like talking) and PIR (passive infrared motion sensing) to determine if there were people in the space and what type of lighting they would need.

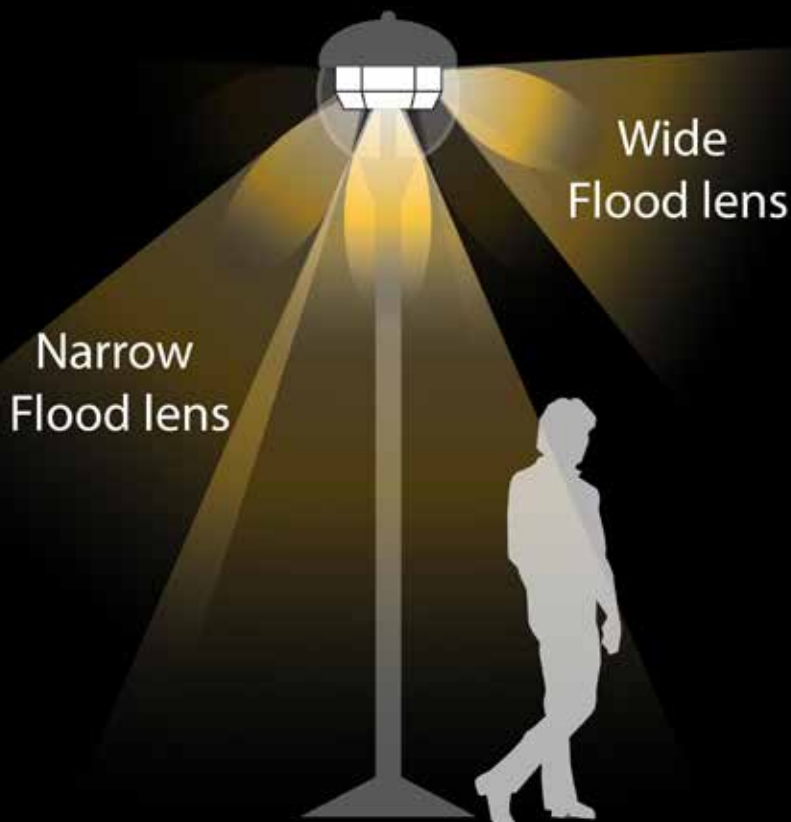
Socializing creates lots of sound and motion.

Transit creates a lot of motion but not sound.

Relaxation is both quiet and still.

On the next section I began researching how these sensors worked and if they would be appropriate for a post-top luminaire.

Elevation View



Detecting People

Finding the right sensors



Sonar

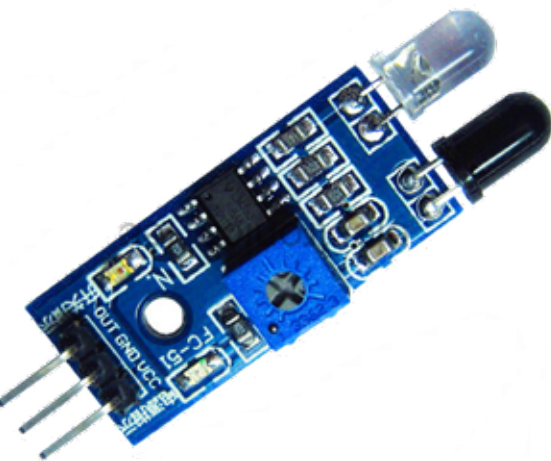
An ultrasonic speaker sends out a pulse. The pulse bounces off an object and back to the microphone. the amount of time it takes lets the sensor determine the distance of the object.

Pros

- Precise distance along the line of the speaker

Cons

- Linear
- Bother wildlife
- Difficult to scale up



Passive Infrared

An IR light shines into a space. Two photosensors measure the same amount of IR bouncing off the space. An object passing through the space interrupts the beam of one sensor, causing an imbalance.

Pros

- Uses lenses to vary sensor range and depth
- Detects hot bodies (won't be detecting trees)

Cons

- Not size variable (can be set off by cars and squirrels)
- Does not detect distance

Computer Vision

The analysis of pixel data from cameras to identify objects and people. This is how snapchat filters and automatic tagging in social media work. Groups and proportions of pixels are analyzed to determine what is there and what it means

Pros

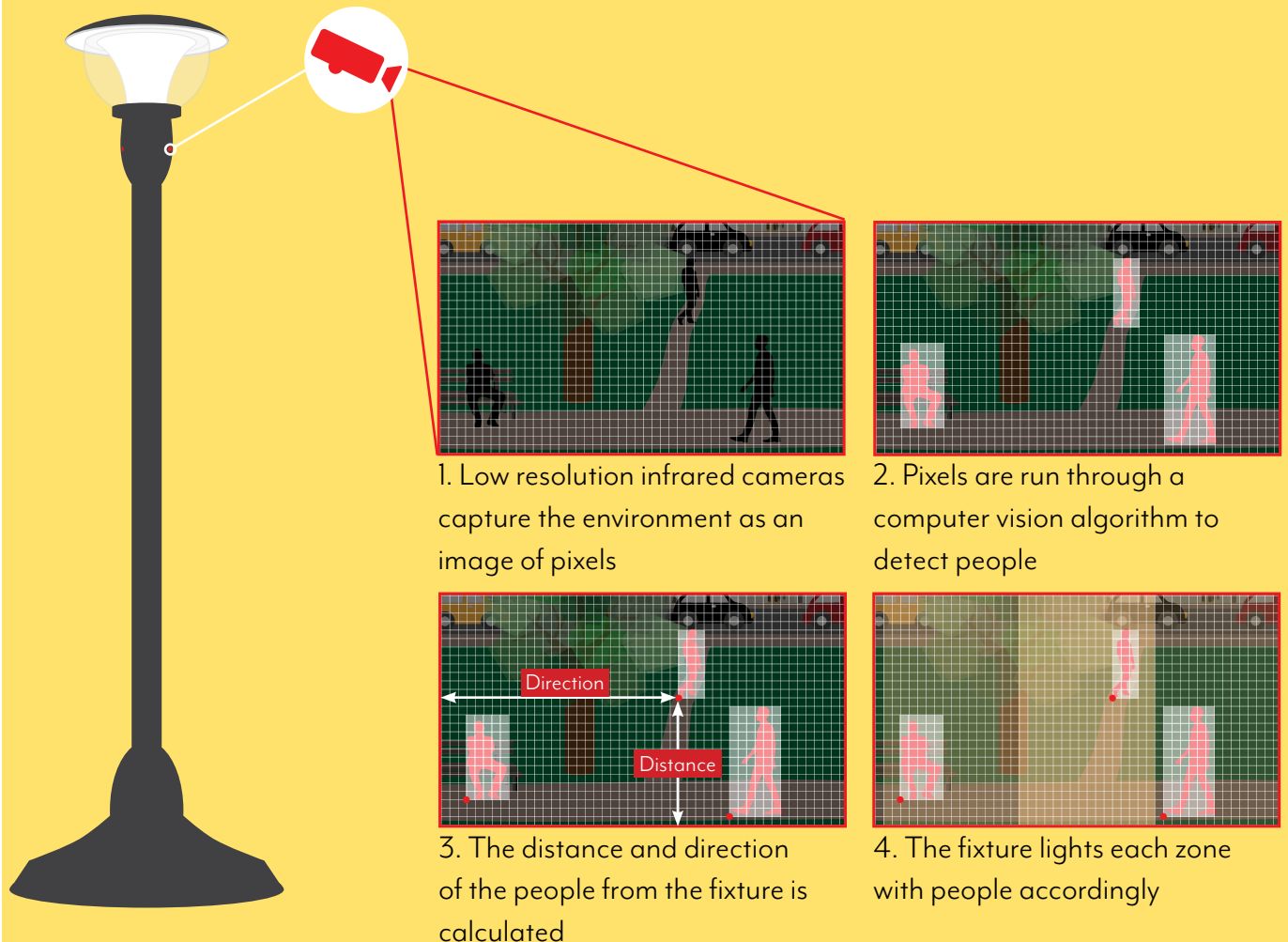
- Only requires a camera
- Multiple types of data can be collected from it (distance, direction, patterns, predictive algorithms)

Cons

- Privacy concerns from cameras in public spaces
- Requires additional computing power for image processing

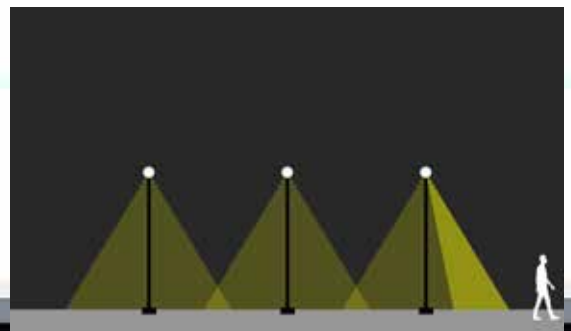


How CV Works



```
sketch_3_Light_Elevation
1 //Sketch frame = 0;
2 int transA = 0;
3 boolean is;
4
5 void setup() {
6   size(1000, 600);
7   s = loadImage("walking Person white.png");
8 }
9
10 void draw() {
11   background(40, 40, 40);
12
13   vertex(200); //low value
14   noStroke();
15
16   fill(150, 150, 150);
17   rect(0, 550, 1000, 600); //width 1000
18
19   fill(255, 255, 0, 50);
20   triangle(150, .5*width, 100, 500, 500);
21   triangle(.5*width, .5*height, 300, 550, 550);
22   triangle(.75*width, .5*height, 600, 550, 550);
23
24   //light A1
25   //mouseX < .15*width){
26   trans = map (mouseX, 0, 150, 0, 255); // convert mouseX between 0 and 150 to transA
27   //mouseX >= .15*width){
28   trans = map (mouseX, 150, 300, 0, 255); // convert mouseX between 300 and 150 to transA
29   fill(255, 255, 0, trans);
30   triangle(150, .5*height, 100, 500, 500);
31
32   //light A2
33   //mouseX < .25*width){
34   trans = map (mouseX, 100, 250, 0, 255); // convert mouseX between 0 and 250 to transA
35   //mouseX >= .25*width){
36   trans = map (mouseX, 400, 250, 0, 255); // convert mouseX between 300 and 150 to transA
37   fill(255, 255, 0, trans);
38   triangle(250, .5*height, 200, 550, 550);
39
40   //light A3
41   //mouseX < .35*width){
42   trans = map (mouseX, 0, 150, 0, 255); // convert mouseX between 0 and 150 to transA
43   //mouseX >= .35*width){
44   trans = map (mouseX, 300, 150, 0, 255); // convert mouseX between 300 and 150 to transA
45   fill(255, 255, 0, trans);
46   triangle(250, .5*height, 300, 500, 500);
47
48   //light A4
49   //mouseX < .45*width){
50   trans = map (mouseX, 100, 250, 0, 255); // convert mouseX between 0 and 250 to transA
51   //mouseX >= .45*width){
52   trans = map (mouseX, 400, 250, 0, 255); // convert mouseX between 300 and 150 to transA
53   fill(255, 255, 0, trans);
54   triangle(250, .5*height, 200, 500, 500);
55
56   //light A5
57   //mouseX < .55*width){
58   trans = map (mouseX, 200, 350, 0, 255); // convert mouseX between 0 and 150 to transA
59   //mouseX >= .55*width){
60   trans = map (mouseX, 500, 350, 0, 255); // convert mouseX between 300 and 150 to transA
61   fill(255, 255, 0, trans);
62   triangle(250, .5*height, 300, 500, 500);
63
64   //light A6
65   //mouseX < .65*width){
66   trans = map (mouseX, 0, 150, 0, 255); // convert mouseX between 0 and 150 to transA
67   //mouseX >= .65*width){
68   trans = map (mouseX, 300, 150, 0, 255); // convert mouseX between 300 and 150 to transA
69   fill(255, 255, 0, trans);
70   triangle(250, .5*height, 300, 500, 500);
71
72   //light A7
73   //mouseX < .75*width){
74   trans = map (mouseX, 100, 250, 0, 255); // convert mouseX between 0 and 250 to transA
75   //mouseX >= .75*width){
76   trans = map (mouseX, 400, 250, 0, 255); // convert mouseX between 300 and 150 to transA
77   fill(255, 255, 0, trans);
78   triangle(250, .5*height, 200, 500, 500);
79
80   //light A8
81   //mouseX < .85*width){
82   trans = map (mouseX, 200, 350, 0, 255); // convert mouseX between 0 and 150 to transA
83   //mouseX >= .85*width){
84   trans = map (mouseX, 500, 350, 0, 255); // convert mouseX between 300 and 150 to transA
85   fill(255, 255, 0, trans);
86   triangle(250, .5*height, 300, 500, 500);
87
88   //light A9
89   //mouseX < .95*width){
90   trans = map (mouseX, 0, 150, 0, 255); // convert mouseX between 0 and 150 to transA
91   //mouseX >= .95*width){
92   trans = map (mouseX, 300, 150, 0, 255); // convert mouseX between 300 and 150 to transA
93   fill(255, 255, 0, trans);
94   triangle(250, .5*height, 300, 500, 500);
95
96   //light A10
97   stroke(80);
98   strokeWeight(4);
99
100   //light A11
101   stroke(80);
102   strokeWeight(4);
103
104   //light A12
105   stroke(80);
106   strokeWeight(4);
107
108   //light A13
109   stroke(80);
110   strokeWeight(4);
111
112   //light A14
113   stroke(80);
114   strokeWeight(4);
115
116   //light A15
117   stroke(80);
118   strokeWeight(4);
119
120   //light A16
121   stroke(80);
122   strokeWeight(4);
123
124   //light A17
125   stroke(80);
126   strokeWeight(4);
127
128   //light A18
129   stroke(80);
130   strokeWeight(4);
131
132   //light A19
133   stroke(80);
134   strokeWeight(4);
135
136   //light A20
137   stroke(80);
138   strokeWeight(4);
139
140   //light A21
141   stroke(80);
142   strokeWeight(4);
143
144   //light A22
145   stroke(80);
146   strokeWeight(4);
147
148   //light A23
149   stroke(80);
150   strokeWeight(4);
151
152   //light A24
153   stroke(80);
154   strokeWeight(4);
155
156   //light A25
157   stroke(80);
158   strokeWeight(4);
159
160   //light A26
161   stroke(80);
162   strokeWeight(4);
163
164   //light A27
165   stroke(80);
166   strokeWeight(4);
167
168   //light A28
169   stroke(80);
170   strokeWeight(4);
171
172   //light A29
173   stroke(80);
174   strokeWeight(4);
175
176   //light A30
177   stroke(80);
178   strokeWeight(4);
179
180   //light A31
181   stroke(80);
182   strokeWeight(4);
183
184   //light A32
185   stroke(80);
186   strokeWeight(4);
187
188   //light A33
189   stroke(80);
190   strokeWeight(4);
191
192   //light A34
193   stroke(80);
194   strokeWeight(4);
195
196   //light A35
197   stroke(80);
198   strokeWeight(4);
199
200   //light A36
201   stroke(80);
202   strokeWeight(4);
203
204   //light A37
205   stroke(80);
206   strokeWeight(4);
207
208   //light A38
209   stroke(80);
210   strokeWeight(4);
211
212   //light A39
213   stroke(80);
214   strokeWeight(4);
215
216   //light A40
217   stroke(80);
218   strokeWeight(4);
219
220   //light A41
221   stroke(80);
222   strokeWeight(4);
223
224   //light A42
225   stroke(80);
226   strokeWeight(4);
227
228   //light A43
229   stroke(80);
230   strokeWeight(4);
231
232   //light A44
233   stroke(80);
234   strokeWeight(4);
235
236   //light A45
237   stroke(80);
238   strokeWeight(4);
239
240   //light A46
241   stroke(80);
242   strokeWeight(4);
243
244   //light A47
245   stroke(80);
246   strokeWeight(4);
247
248   //light A48
249   stroke(80);
250   strokeWeight(4);
251
252   //light A49
253   stroke(80);
254   strokeWeight(4);
255
256   //light A50
257   stroke(80);
258   strokeWeight(4);
259
260   //light A51
261   stroke(80);
262   strokeWeight(4);
263
264   //light A52
265   stroke(80);
266   strokeWeight(4);
267
268   //light A53
269   stroke(80);
270   strokeWeight(4);
271
272   //light A54
273   stroke(80);
274   strokeWeight(4);
275
276   //light A55
277   stroke(80);
278   strokeWeight(4);
279
280   //light A56
281   stroke(80);
282   strokeWeight(4);
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284   //light A57
285   stroke(80);
286   strokeWeight(4);
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288   //light A58
289   stroke(80);
290   strokeWeight(4);
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292   //light A59
293   stroke(80);
294   strokeWeight(4);
295
296   //light A60
297   stroke(80);
298   strokeWeight(4);
299
300   //light A61
301   stroke(80);
302   strokeWeight(4);
303
304   //light A62
305   stroke(80);
306   strokeWeight(4);
307
308   //light A63
309   stroke(80);
310   strokeWeight(4);
311
312   //light A64
313   stroke(80);
314   strokeWeight(4);
315
316   //light A65
317   stroke(80);
318   strokeWeight(4);
319
320   //light A66
321   stroke(80);
322   strokeWeight(4);
323
324   //light A67
325   stroke(80);
326   strokeWeight(4);
327
328   //light A68
329   stroke(80);
330   strokeWeight(4);
331
332   //light A69
333   stroke(80);
334   strokeWeight(4);
335
336   //light A70
337   stroke(80);
338   strokeWeight(4);
339
340   //light A71
341   stroke(80);
342   strokeWeight(4);
343
344   //light A72
345   stroke(80);
346   strokeWeight(4);
347
348   //light A73
349   stroke(80);
350   strokeWeight(4);
351
352   //light A74
353   stroke(80);
354   strokeWeight(4);
355
356   //light A75
357   stroke(80);
358   strokeWeight(4);
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360   //light A76
361   stroke(80);
362   strokeWeight(4);
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364   //light A77
365   stroke(80);
366   strokeWeight(4);
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368   //light A78
369   stroke(80);
370   strokeWeight(4);
371
372   //light A79
373   stroke(80);
374   strokeWeight(4);
375
376   //light A80
377   stroke(80);
378   strokeWeight(4);
379
380   //light A81
381   stroke(80);
382   strokeWeight(4);
383
384   //light A82
385   stroke(80);
386   strokeWeight(4);
387
388   //light A83
389   stroke(80);
390   strokeWeight(4);
391
392   //light A84
393   stroke(80);
394   strokeWeight(4);
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396   //light A85
397   stroke(80);
398   strokeWeight(4);
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400   //light A86
401   stroke(80);
402   strokeWeight(4);
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404   //light A87
405   stroke(80);
406   strokeWeight(4);
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408   //light A88
409   stroke(80);
410   strokeWeight(4);
411
412   //light A89
413   stroke(80);
414   strokeWeight(4);
415
416   //light A90
417   stroke(80);
418   strokeWeight(4);
419
420   //light A91
421   stroke(80);
422   strokeWeight(4);
423
424   //light A92
425   stroke(80);
426   strokeWeight(4);
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428   //light A93
429   stroke(80);
430   strokeWeight(4);
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432   //light A94
433   stroke(80);
434   strokeWeight(4);
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436   //light A95
437   stroke(80);
438   strokeWeight(4);
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440   //light A96
441   stroke(80);
442   strokeWeight(4);
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444   //light A97
445   stroke(80);
446   strokeWeight(4);
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448   //light A98
449   stroke(80);
450   strokeWeight(4);
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452   //light A99
453   stroke(80);
454   strokeWeight(4);
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456   //light A100
457   stroke(80);
458   strokeWeight(4);
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460   //light A101
461   stroke(80);
462   strokeWeight(4);
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464   //light A102
465   stroke(80);
466   strokeWeight(4);
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468   //light A103
469   stroke(80);
470   strokeWeight(4);
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472   //light A104
473   stroke(80);
474   strokeWeight(4);
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476   //light A105
477   stroke(80);
478   strokeWeight(4);
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480   //light A106
481   stroke(80);
482   strokeWeight(4);
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484   //light A107
485   stroke(80);
486   strokeWeight(4);
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488   //light A108
489   stroke(80);
490   strokeWeight(4);
491
492   //light A109
493   stroke(80);
494   strokeWeight(4);
495
496   //light A110
497   stroke(80);
498   strokeWeight(4);
499
500   //light A111
501   stroke(80);
502   strokeWeight(4);
503
504   //light A112
505   stroke(80);
506   strokeWeight(4);
507
508   //light A113
509   stroke(80);
510   strokeWeight(4);
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512   //light A114
513   stroke(80);
514   strokeWeight(4);
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516   //light A115
517   stroke(80);
518   strokeWeight(4);
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520   //light A116
521   stroke(80);
522   strokeWeight(4);
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524   //light A117
525   stroke(80);
526   strokeWeight(4);
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528   //light A118
529   stroke(80);
530   strokeWeight(4);
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532   //light A119
533   stroke(80);
534   strokeWeight(4);
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536   //light A120
537   stroke(80);
538   strokeWeight(4);
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540   //light A121
541   stroke(80);
542   strokeWeight(4);
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544   //light A122
545   stroke(80);
546   strokeWeight(4);
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548   //light A123
549   stroke(80);
550   strokeWeight(4);
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552   //light A124
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554   strokeWeight(4);
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556   //light A125
557   stroke(80);
558   strokeWeight(4);
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560   //light A126
561   stroke(80);
562   strokeWeight(4);
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564   //light A127
565   stroke(80);
566   strokeWeight(4);
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568   //light A128
569   stroke(80);
570   strokeWeight(4);
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572   //light A129
573   stroke(80);
574   strokeWeight(4);
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576   //light A130
577   stroke(80);
578   strokeWeight(4);
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580   //light A131
581   stroke(80);
582   strokeWeight(4);
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584   //light A132
585   stroke(80);
586   strokeWeight(4);
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588   //light A133
589   stroke(80);
590   strokeWeight(4);
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592   //light A134
593   stroke(80);
594   strokeWeight(4);
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596   //light A135
597   stroke(80);
598   strokeWeight(4);
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600   //light A136
601   stroke(80);
602   strokeWeight(4);
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604   //light A137
605   stroke(80);
606   strokeWeight(4);
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608   //light A138
609   stroke(80);
610   strokeWeight(4);
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612   //light A139
613   stroke(80);
614   strokeWeight(4);
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616   //light A140
617   stroke(80);
618   strokeWeight(4);
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620   //light A141
621   stroke(80);
622   strokeWeight(4);
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624   //light A142
625   stroke(80);
626   strokeWeight(4);
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628   //light A143
629   stroke(80);
630   strokeWeight(4);
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632   //light A144
633   stroke(80);
634   strokeWeight(4);
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636   //light A145
637   stroke(80);
638   strokeWeight(4);
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640   //light A146
641   stroke(80);
642   strokeWeight(4);
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644   //light A147
645   stroke(80);
646   strokeWeight(4);
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648   //light A148
649   stroke(80);
650   strokeWeight(4);
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652   //light A149
653   stroke(80);
654   strokeWeight(4);
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656   //light A150
657   stroke(80);
658   strokeWeight(4);
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660   //light A151
661   stroke(80);
662   strokeWeight(4);
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664   //light A152
665   stroke(80);
666   strokeWeight(4);
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669   stroke(80);
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681   stroke(80);
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684   //light A157
685   stroke(80);
686   strokeWeight(4);
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688   //light A158
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692   //light A159
693   stroke(80);
694   strokeWeight(4);
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696   //light A160
697   stroke(80);
698   strokeWeight(4);
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700   //light A161
701   stroke(80);
702   strokeWeight(4);
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704   //light A162
705   stroke(80);
706   strokeWeight(4);
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708   //light A163
709   stroke(80);
710   strokeWeight(4);
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712   //light A164
713   stroke(80);
714   strokeWeight(4);
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716   //light A165
717   stroke(80);
718   strokeWeight(4);
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720   //light A166
721   stroke(80);
722   strokeWeight(4);
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724   //light A167
725   stroke(80);
726   strokeWeight(4);
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728   //light A168
729   stroke(80);
730   strokeWeight(4);
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732   //light A169
733   stroke(80);
734   strokeWeight(4);
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736   //light A170
737   stroke(80);
738   strokeWeight(4);
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740   //light A171
741   stroke(80);
742   strokeWeight(4);
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744   //light A172
745   stroke(80);
746   strokeWeight(4);
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748   //light A173
749   stroke(80);
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752   //light A174
753   stroke(80);
754   strokeWeight(4);
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756   //light A175
757   stroke(80);
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760   //light A176
761   stroke(80);
762   strokeWeight(4);
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765   stroke(80);
766   strokeWeight(4);
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768   //light A178
769   stroke(80);
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772   //light A179
773   stroke(80);
774   strokeWeight(4);
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776   //light A180
777   stroke(80);
778   strokeWeight(4);
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780   //light A181
781   stroke(80);
782   strokeWeight(4);
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784   //light A182
785   stroke(80);
786   strokeWeight(4);
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788   //light A183
789   stroke(80);
790   strokeWeight(4);
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792   //light A184
793   stroke(80);
794   strokeWeight(4);
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796   //light A185
797   stroke(80);
798   strokeWeight(4);
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801   stroke(80);
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804   //light A187
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809   stroke(80);
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813   stroke(80);
814   strokeWeight(4);
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816   //light A190
817   stroke(80);
818   strokeWeight(4);
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820   //light A191
821   stroke(80);
822   strokeWeight(4);
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824   //light A192
825   stroke(80);
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828   //light A193
829   stroke(80);
830   strokeWeight(4);
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832   //light A194
833   stroke(80);
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836   //light A195
837   stroke(80);
838   strokeWeight(4);
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840   //light A196
841   stroke(80);
842   strokeWeight(4);
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844   //light A197
845   stroke(80);
846   strokeWeight(4);
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848   //light A198
849   stroke(80);
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852   //light A199
853   stroke(80);
854   strokeWeight(4);
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856   //light A200
857   stroke(80);
858   strokeWeight(4);
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860   //light A201
861   stroke(80);
862   strokeWeight(4);
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864   //light A202
865   stroke(80);
866   strokeWeight(4);
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868   //light A203
869   stroke(80);
870   strokeWeight(4);
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872   //light A204
873   stroke(80);
874   strokeWeight(4);
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876   //light A205
877   stroke(80);
878   strokeWeight(4);
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880   //light A206
881   stroke(80);
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885   stroke(80);
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893   stroke(80);
894   strokeWeight(4);
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896   //light A210
897   stroke(80);
898   strokeWeight(4);
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900   //light A211
901   stroke(80);
902   strokeWeight(4);
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904   //light A212
905   stroke(80);
906   strokeWeight(4);
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908   //light A213
909   stroke(80);
910   strokeWeight(4);
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912   //light A214
913   stroke(80);
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916   //light A215
917   stroke(80);
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920   //light A216
921   stroke(80);
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924   //light A217
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929   stroke(80);
930   strokeWeight(4);
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932   //light A219
933   stroke(80);
934   strokeWeight(4);
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936   //light A220
937   stroke(80);
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940   //light A221
941   stroke(80);
942   strokeWeight(4);
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944   //light A222
945   stroke(80);
946   strokeWeight(4);
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948   //light A223
949   stroke(80);
950   strokeWeight(4);
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952   //light A224
953   stroke(80);
954   strokeWeight(4);
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956   //light A225
957   stroke(80);
958   strokeWeight(4);
959
960   //light A226
961   stroke(80);
962   strokeWeight(4);
963
964   //light A227
965   stroke(80);
966   strokeWeight(4);
967
968   //light A228
969   stroke(80);
970   strokeWeight(4);
971
972   //light A229
973   stroke(80);
974   strokeWeight(4);
975
976   //light A230
977   stroke(80);
978   strokeWeight(4);
979
980   //light A231
981   stroke(80);
982   strokeWeight(4);
983
984   //light A232
985   stroke(80);
986   strokeWeight(4);
987
988   //light A233
989   stroke(80);
990   strokeWeight(4);
991
992   //light A234
993   stroke(80);
994   strokeWeight(4);
995
996   //light A235
997   stroke(80);
998   strokeWeight(4);
999
1000   //light A236
1001   stroke(80);
1002   strokeWeight(4);
1003
1004   //light A237
1005   stroke(80);
1006   strokeWeight(4);
1007
1008   //light A238
1009   stroke(80);
1010   strokeWeight(4);
1011
1012   //light A239
1013   stroke(80);
1014   strokeWeight(4);
1015
1016   //light A240
1017   stroke(80);
1018   strokeWeight(4);
1019
1020   //light A241
1021   stroke(80);
1022   strokeWeight(4);
1023
1024   //light A242
1025   stroke(80);
1026   strokeWeight(4);
1027
1028   //light A243
1029   stroke(80);
1030   strokeWeight(4);
1031
1032   //light A244
1033   stroke(80);
1034   strokeWeight(4);
1035
1036   //light A245
1037   stroke(80);
1038   strokeWeight(4);
1039
1040   //light A246
1041   stroke(80);
1042   strokeWeight(4);
1043
1044   //light A247
1045   stroke(80);
1046   strokeWeight(4);
1047
1048   //light A248
1049   stroke(80);
1050   strokeWeight(4);
1051
1052   //light A249
1053   stroke(80);
1054   strokeWeight(4);
1055
1056   //light A250
1057   stroke(80);
1058   strokeWeight(4);
1059
1060   //light A251
1061   stroke(80);
1062   strokeWeight(4);
1063
1064   //light A252
1065   stroke(80);
1066   strokeWeight(4);
1067
1068   //light A253
1069   stroke(80);
1070   strokeWeight(4);
1071
1072   //light A254
1073   stroke(80);
1074   strokeWeight(4);
1075
1076   //light A255
1077   stroke(80);
1078   strokeWeight(4);
1079
1080   //light A256
1081   stroke(80);
1082   strokeWeight(4);
1083
1084   //light A257
1085   stroke(80);
1086   strokeWeight(4);
1087
1088   //light A258
1089   stroke(80);
1090   strokeWeight(4);
1091
1092   //light A259
1093   stroke(80);
1094   strokeWeight(4);
1095
1096   //light A260
1097   stroke(80);
1098   strokeWeight(4);
1099
1100   //light A261
1101   stroke(80);
1102   strokeWeight(4);
1103
1104   //light A262
1105   stroke(80);
1106   strokeWeight(4);
1107
1108   //light A263
1109   stroke(80);
1110   strokeWeight(4);
1111
1112   //light A264
1113   stroke(80);
1114   strokeWeight(4);
1115
1116   //light A265
1117   stroke(80);
1118   strokeWeight(4);
1119
1120   //light A266
1121   stroke(80);
1122   strokeWeight(4);
1123
1124   //light A267
1125   stroke(80);
1126   strokeWeight(4);
1127
1128   //light A268
1129   stroke(80);
1130   strokeWeight(4);
1131
1132   //light A269
1133   stroke(80);
1134   strokeWeight(4);
1135
1136   //light A270
1137   stroke(80);
1138   strokeWeight(4);
1139
1140   //light A271
1141   stroke(80);
1142   strokeWeight(4);
1143
1144   //light A272
1145   stroke(80);
1146   strokeWeight(4);
1147
1148   //light A273
1149   stroke(80);
1150   strokeWeight(4);
1151
1152   //light A274
1153   stroke(80);
1154   strokeWeight(4);
1155
1156   //light A275
1157   stroke(80);
1158   strokeWeight(4);
1159
1160   //light A276
1161   stroke(80);
1162   strokeWeight(4);
1163
1164   //light A277
1165   stroke(80);
1166   strokeWeight(4);
1167
1168   //light A278
1169   stroke(80);
1170   strokeWeight(4);
1171
1172   //light A279
1173   stroke(80);
1174   strokeWeight(4);
1175
1176   //light A280
1177   stroke(80);
1178   strokeWeight(4);
1179
1180   //light A281
1181   stroke(80);
1182   strokeWeight(4);
1183
1184   //light A282
1185   stroke(80);
1186   strokeWeight(4);
1187
1188   //light A283
1189   stroke(80);
1190   strokeWeight(4);
1191
1192   //light A284
1193   stroke(80);
1194   strokeWeight(4);
1195
1196   //light A285
1197   stroke(80);
1198   strokeWeight(4);
1199
1200   //light A286
1201   stroke(80);
1202   strokeWeight(4);
1203
1204   //light A287
1205   stroke(80);
1206   strokeWeight(4);
1207
1208   //light A288
1209   stroke(80);
1210   strokeWeight(4);
1211
1212   //light A289
1213   stroke(80);
1214   strokeWeight(4);
1215
1216   //light A290
1217   stroke(80);
1218   strokeWeight(4);
1219
1220   //light A291
1221   stroke(80);
1222   strokeWeight(4);
1223
1224   //light A292
1225   stroke(80);
1226   strokeWeight(4);
1227
1228   //light A293
1229   stroke(80);
1230   strokeWeight(4);
1231
1232   //light A294
1233   stroke(80);
1234   strokeWeight(4);
1235
1236   //light A295
1237   stroke(80);
1238   strokeWeight(4);
1239
1240   //light A296
1241   stroke(80);
1242   strokeWeight(4);
1243
1244   //light A297
1245   stroke(80);
1246   strokeWeight(4);
1247
1248   //light A298
1249   stroke(80);
1250   strokeWeight(4);
1251
1252   //light A299
1253   stroke(80);
1254   strokeWeight(4);
1255
1256   //light A300
1257   stroke(80);
1258   strokeWeight(4);
1259
1260   //light A301
1261   stroke(80);
1262   strokeWeight(4);
1263
1264   //light A3
```

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Sensor Prototyping with Arduino

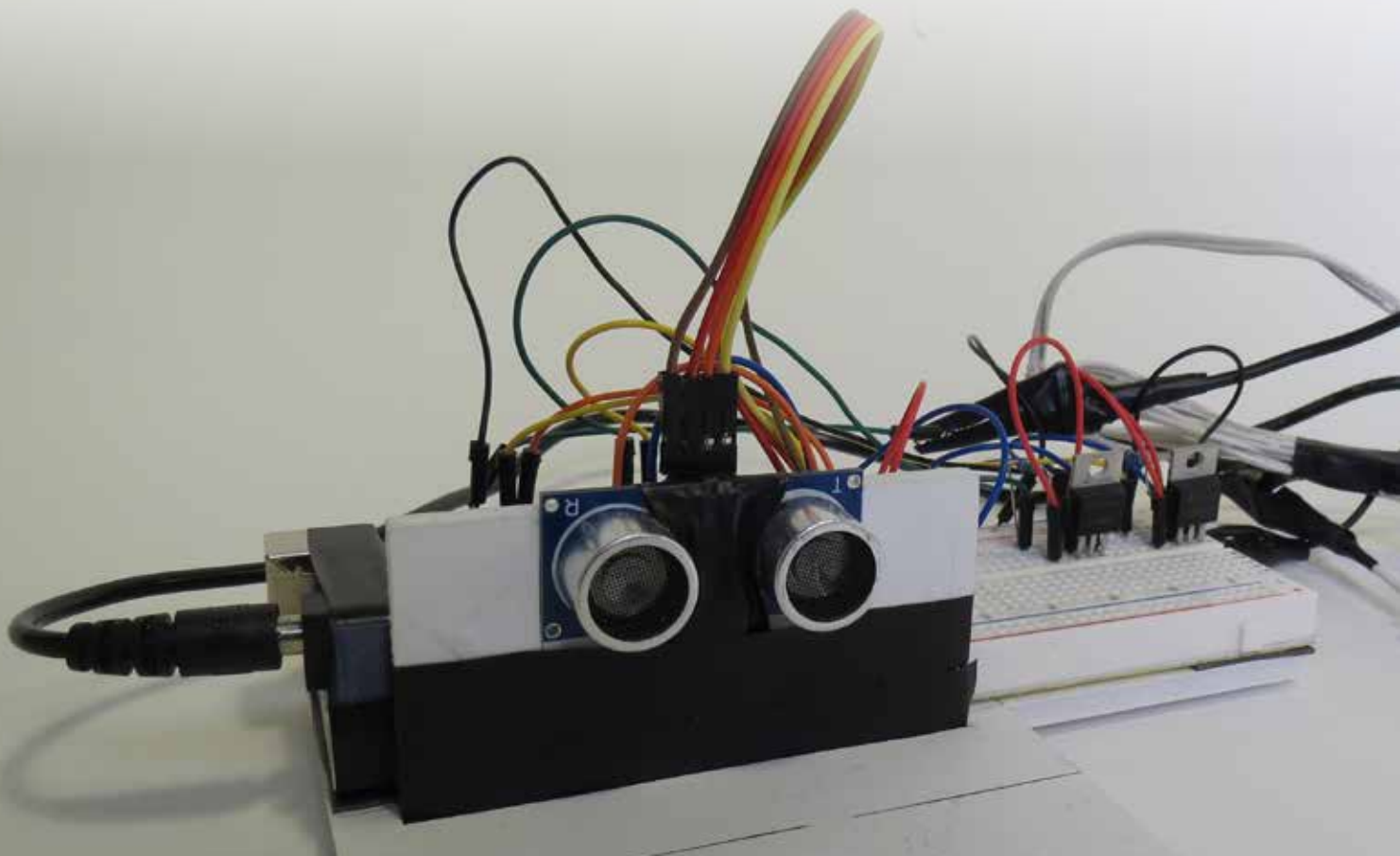
The next stage was to simulate the interaction with real lights. For this I used a setup shown below, which consisted of:

- 3 LED diodes of different colors (to make differentiating them in the code easier)
- Sonic distance sensor (one side sends out a pulse, the other side receives the “echo” of the pulse off of an object).
- A board that marked off each centimeter (each centimeter equal one foot to show scale).

This set up would simulate 3 non-directional light poles along a path. It had to be along a path because the sonic sensor can only detect in a straight line. It had to use the sonic sensor because I needed an accurate (1cm = 1ft) distance.

The code was written so each LED connected to a pin on the Arduino board that could use PWM (pulse with modulation.) PWM is the way to digitally simulate analog dimming by turning the light on and off faster than the human eye can detect. The ratio of time off to time on makes the light appear dimmer or brighter.

Each LED was set to a brightness determined by the distance detected by the sonic sensor. I coded in 5cm sections to make the coding go faster. Each LED was at 100% brightness when the object parallel with the diode, and at 20% when the object was at the next LED.



```

Sonic_to__3_LED_brightness.ino

const int echoPin = 12;
////SR04 sr04 = SR04(ECHO_PIN,TRIG_PIN);
long a;

int Y = 3;
int G = 5;

void setup() {
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode (Y, OUTPUT);
  pinMode (G, OUTPUT);

  Serial.begin(9600);
  delay(10);
}

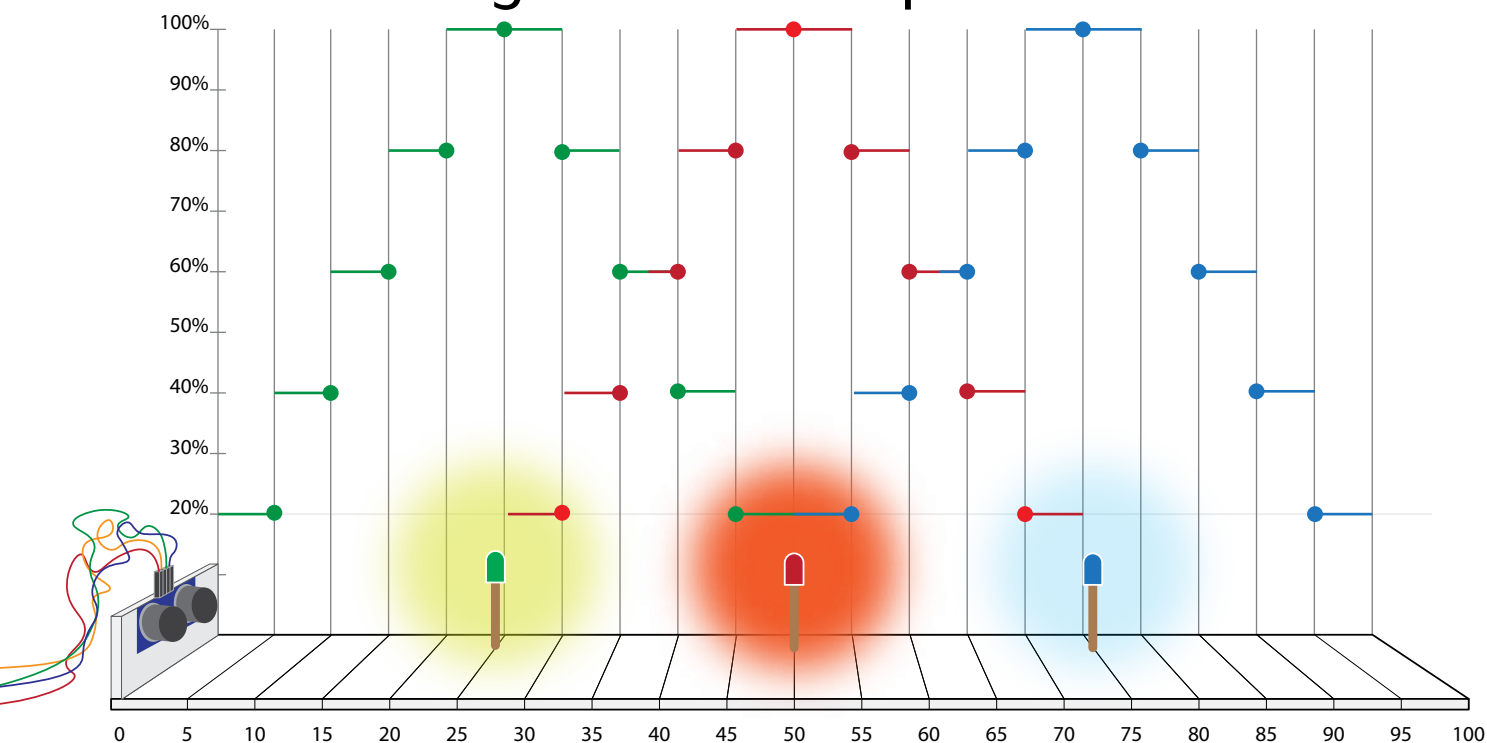
void loop() {
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  int duration = pulseIn(echoPin, HIGH);
  int distance = (duration*.0343)/2;
  Serial.print("Distance: ");
  Serial.println(distance);
  delay(100);

  if (distance < 36 && distance > 0 ){
    analogWrite(Y, 255);
  }
  if (distance > 36){
    analogWrite(Y, 0);
  }

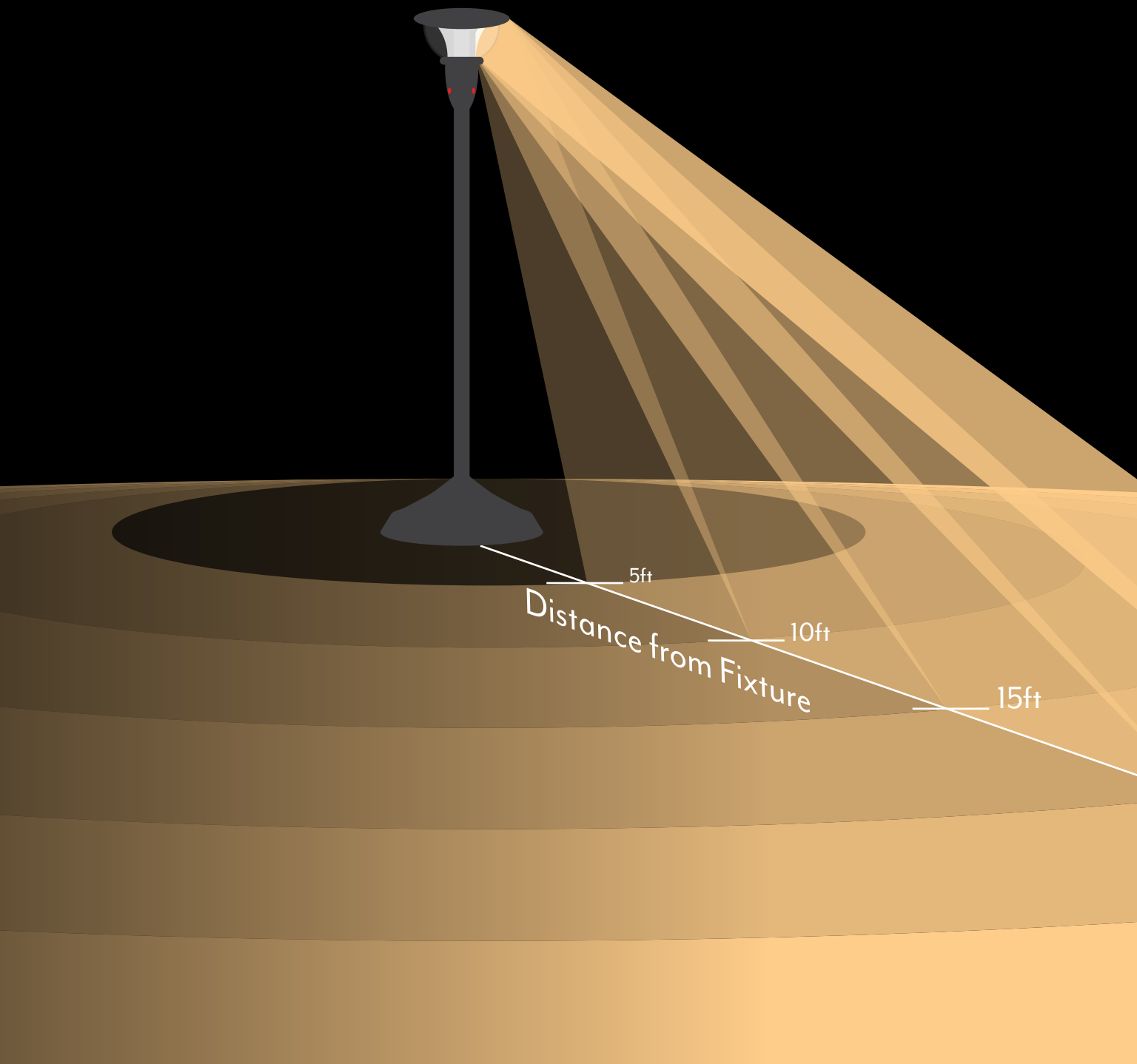
  if (distance > 36 ){
    analogWrite(G, 255);
  }
  if (distance < 36){

```

Light Levels Graph 1



Brightness and Distance

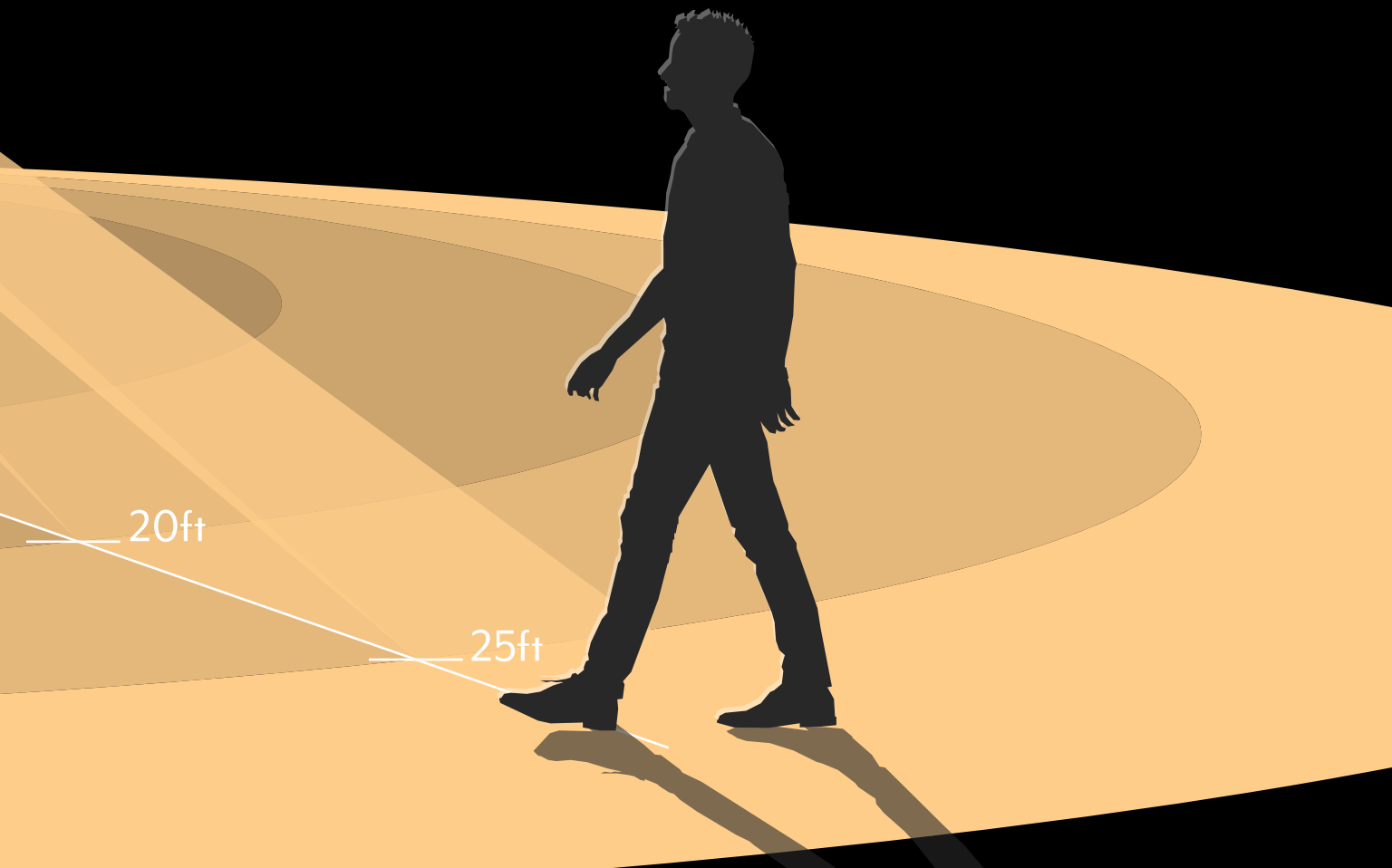


One criteria in my initial concept was that the light should vary depending on the activities of the people in the space. This criteria was discarded because the capabilities of the sensors available cannot distinguish between the different activities, and assumes lighting needs that are not universal from person to person.

The next iteration of that design criteria - that the light should use dynamic dimming, is that the **brightness of the light should be related to the distance that a person is from the fixture.**

The first visualizations always showed the light getting brighter as the person got closer, but I realized this would be a waste of both light and energy. A normal lamp is already going to create a brighter area closer to itself, so a smart fixture would do the opposite.

The light should be brighter when a person is further away to reach across the distance to provide light on the ground and surroundings, then it should dim as the person approaches because the closer you are to the source, the more light is received. The overall effect would be a constant level of illumination where the person is, regardless of the distance from the pole.



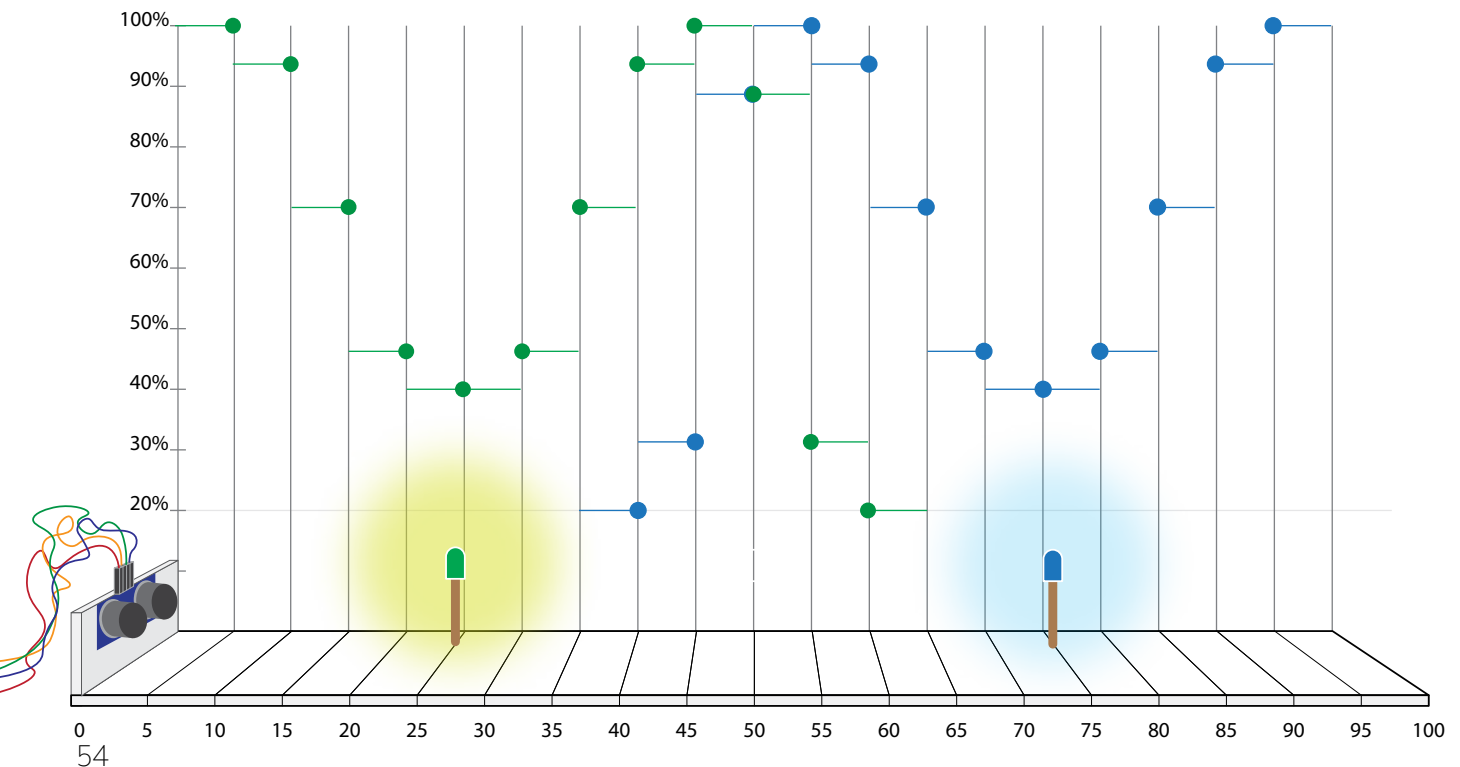
Brightness and Distance Arduino

After proving that the arduino setup with the linear placement of the LEDs and the Socin distance sensor at one end was effective, I went about refining the light interaction.

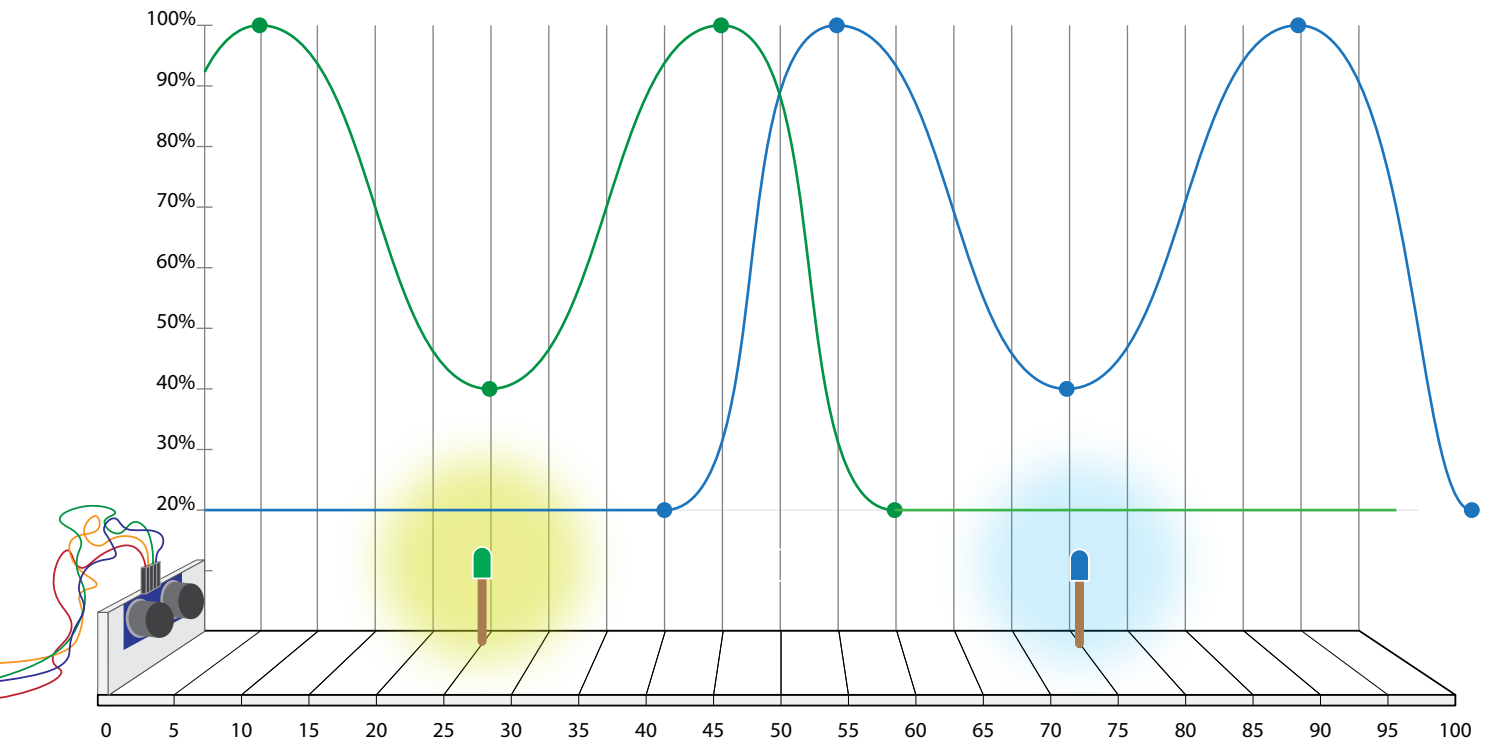
The next change was to match the new criteria of brightness and distance: The light should be **brightest at the furthest distance from the pole.**

The first change I made was to eliminate one of the LED diodes for a more accurate representation of the fixture spacing. The light given off by a pole mounted luminaire typically reaches a radius equal to 2 - 3 times the height of the pole. A standard pedestrian pole is between 8ft and 15ft tall. To keep the numbers even I used a 12ft pole and assumed a light spread radius of 2.5, spacing the poles about 50ft (50cm in the scale model).

Light Levels Graph 2



Light Levels Graph 3



The third iteration of the linear arduino model was to refine the interaction into smooth, continuous dimming. The resulting function is a combination of a sine wave function and a parabolic function. The sharp rise and decline on the ends is parabolic, the middle is a stretched sine curve.

When a person is outside of the range of a fixture, it dims down to 20% to save power.

This scale model is accurately showing the exchange of light between fixtures and the exchange of light between the directional beams in a single fixture.

Illuminance Level Code

How bright do pedestrian spaces need to be?

The brightness of a space is determined by the amount of light hitting each surface in the space. Depending on the space, some surfaces are more important than others. For example, the brightness of a space can be measured by the amount of light hitting the top of a work surface like a desk, or by the light hitting a wall, or the floor. Pedestrian spaces are almost always measured by the brightness of the ground.

The brightness of a surface is measured or calculated (in a light rendering program such as AGi32) with a light meter at points along the surface. The brightness is the amount of light hitting the point, called the illuminance level, measured in foot candles (fc).

How bright each type of space needs to be is laid out in the Illumination Engineering Society (IES) handbook. For example, the brightness of the sidewalk and crosswalk at a busy intersection needs to be 3fc.

That is very, very bright for an outdoor environment at night. A better average for pedestrian spaces would be 1.5fc - 2fc average. Of course, these are maximum values when the fixture is at its brightest. The dynamic dimming with distance of the luminaire I am designing would actually be giving off much less light most of the time. But the maximum brightness should be 2fc at 25ft away from the light pole.



The crosswalk of this busy intersection in Boston should have 3fc on the ground to make sure that pedestrians can be seen by cars.

How bright does this luminaire need to be?

The resource available for this project mean I am designing this luminaire without the equipment and experts that a manufacturing company would have available. These include optical engineers, electrical engineers, and a very expensive system that measures the light coming from the fixture in direction and intensity. So I am working backwards, designing the lighting environment, then the fixture, then determining the light source and optical lenses that need to be used to produce the effect I am designing.

Each led chip or directional beam must be capable of producing 2fc of illumination on the ground 25 ft away from the pole.

The IES publishes a very large book with lots of charts that say what the standard brightness for every space, surface, and situation. Meeting the IES standards is important, because this is the book the lawyers check for liability.



Light Pollution and LEDs

The affordability of LEDs is making it much less expensive to light more at night, and brighter. This is having some unfortunate impacts on our environment, including our health, the wellness of plants and wildlife, and of course, poor astronomers who can no longer see the stars.

In all seriousness though: Light pollution is a growing problem, and LEDs are making it worse.

Only recently have we been able to measure the brightness of the earth's surface: and the numbers now show that it is increasing both in brightness and surface area at a rate of 5% per year.

Three Types of Light Pollution

- **Skyglow** - the light pollution that is caused by light from lots of sources being reflected back into the atmosphere. Skyglow is responsible for most of the damage to the environment: plants, wildlife, and people all **need true darkness at night** in order to maintain their circadian cycles.
- **Light Trespass** - This is the light pollution that comes from light landing where it is not supposed to - such as a traffic light shining into a bedroom window at night. Light's directional control makes this the easiest form of light pollution to address, by simply not turning on the light in the directions that would create light trespass.



Addressing Light Pollution

- **Glare** - This is the form of light pollution when the light is **too bright**. We experience glare as pain in our eyes, and it also damages our eyes. For Ray to be a light that addresses the human experience, glare reduction should be a design priority.



Glare from streetlights



Light trespass in a residential neighborhood

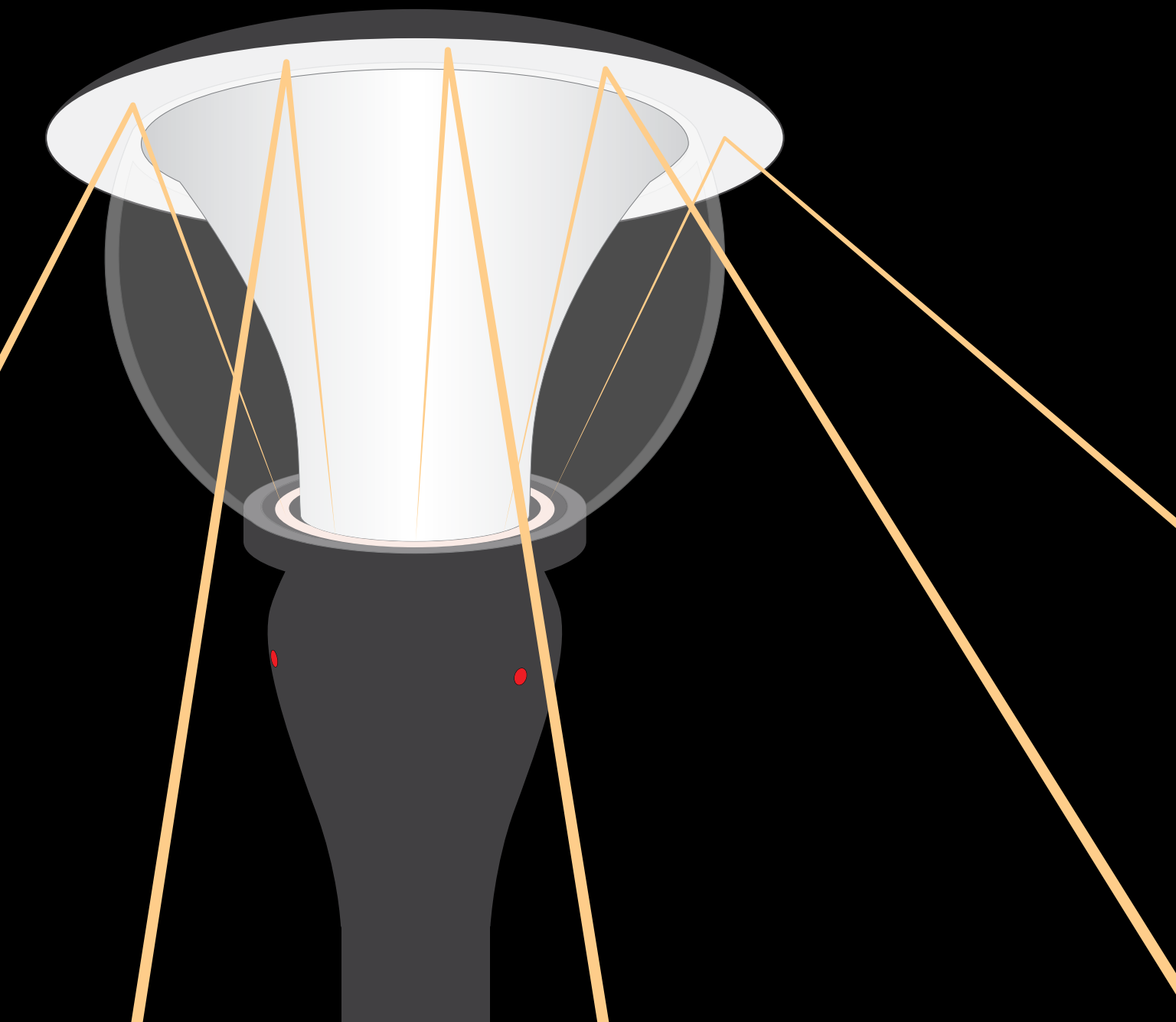


Normal skyglow compared to during a power outage

Benchmark 5

**The fixture should be
designed to reduce its
impact on growing light
pollution**

Indirect Light Source



Indirect light sources have the lamp of the luminaire (in this case the LED chips) out of the line of sight. This makes it impossible to look directly at the bright light (the main cause of glare.) The light that enters the space is bounce from the lamp onto a reflector. The reflector is a smooth matte white surface that diffuses the light so it is less painful to look at but still spreads around the space.



Direct Light Source





In a direct light source the lamping is visible to the eye and the light is streaming directly from the lamp into the environment.

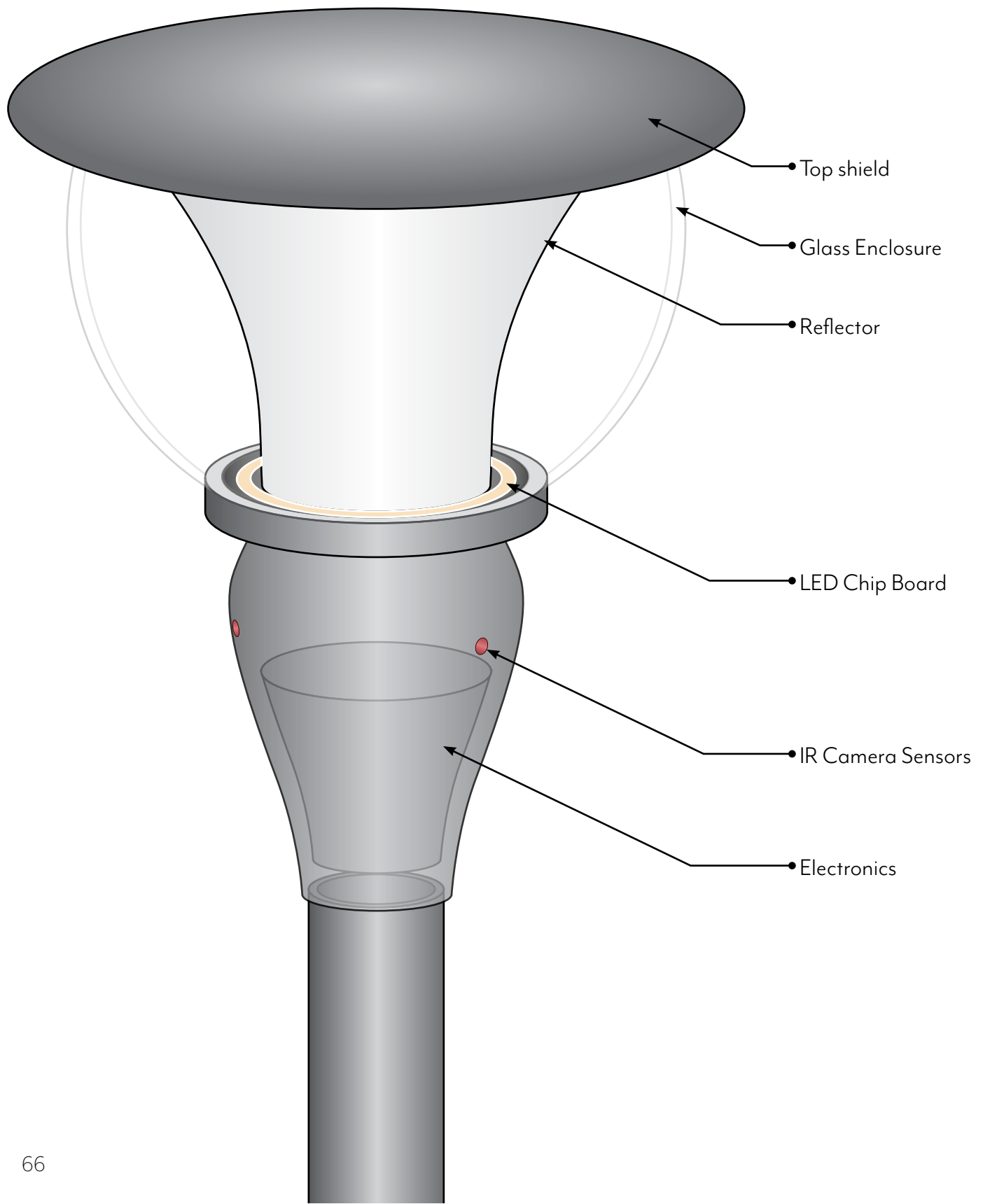
Even in photographs, direct light sources create glare . Sometimes the photographic effect is pretty, but it person it hurts the eyes.

Direct light sources do have the advantage of being more directional, which is a key design criteria. This early concept rendering shows the directional light coming from six angled LED panels with the sensors embedded in the center.

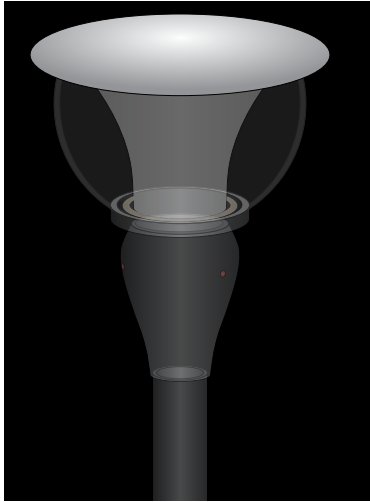
After research and further iterations, I decided that the glare the direct lighting produced, combined with the dynamic dimming, would make the panels look glitchy, and remove some of the mystery of the lighting experience.

The challenge of producing directional light with an indirect source remained, but the advantage of reducing glare in pedestrians' eyes was worth it.

Key Components

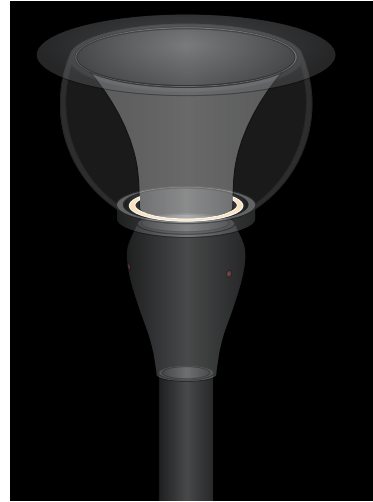


Materials and Processes



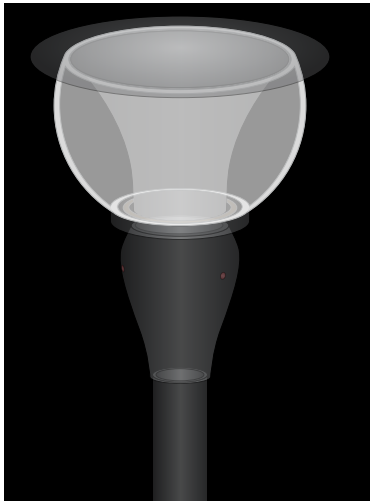
Top shield

- This component prevents light from going up into the sky, addressing the skyglow aspect of light pollution



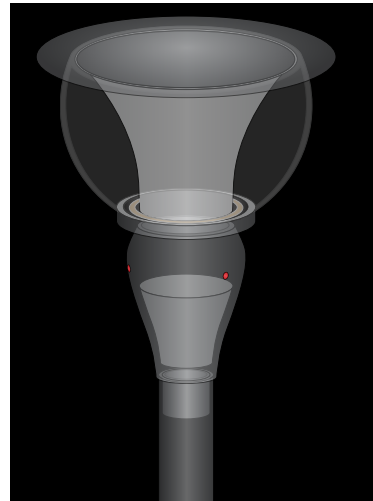
LED Chip Board

- The LED chips are built into a circular circuit board, that is wired to allow each LED to be controlled separately



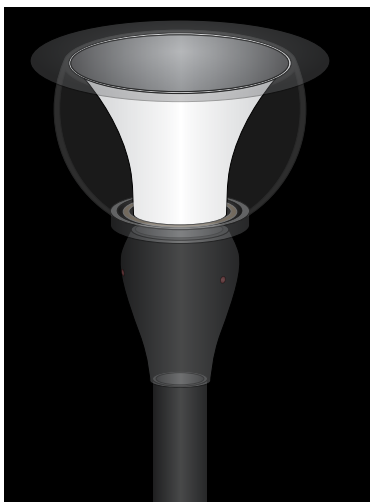
Glass Enclosure

- Clear blow molded glass will seal the LEDs and reflector from bugs, dirt, and weather



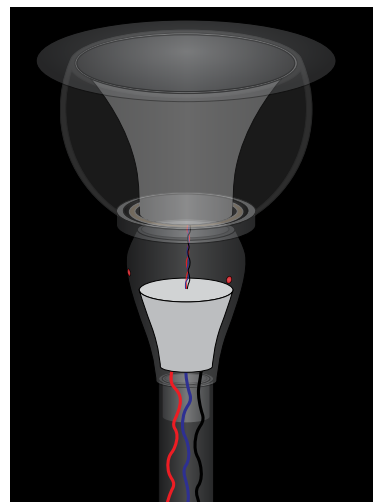
IR Camera Sensor

- The cameras are set into the sensor hub, which houses both the cameras and the image processing and controlling electronics



Reflector

- Spun aluminum is powder coated a smooth matte white. The hollow form houses the passive heat sink for the LEDs



Electronics

- The electronics are weather proofed by potting in a low heat resin. Wire ports for power and data run out the top and bottom of the block for simple installation.

Styles of Light Pole

After identifying the key components I was able to understand how to shape the components to give Ray different styles. To determine what those style should be, I consulted with Inga Birkenstock on the fixtures that she preferred to specify. By analyzing her list and cross referencing with other manufactures, I determined there were 5 main appearance families.



Inga Birkenstock is the principal of Birkenstock Lighting Design. She has 30 years experience in lighting and interior design.



The modern style is characterized by volumous shapes that combine multiple volumes with curves and geometric forms.

The traditional style is a more historic look. Features of this style include finials, fluted poles, and flat panes of glass enclosure.

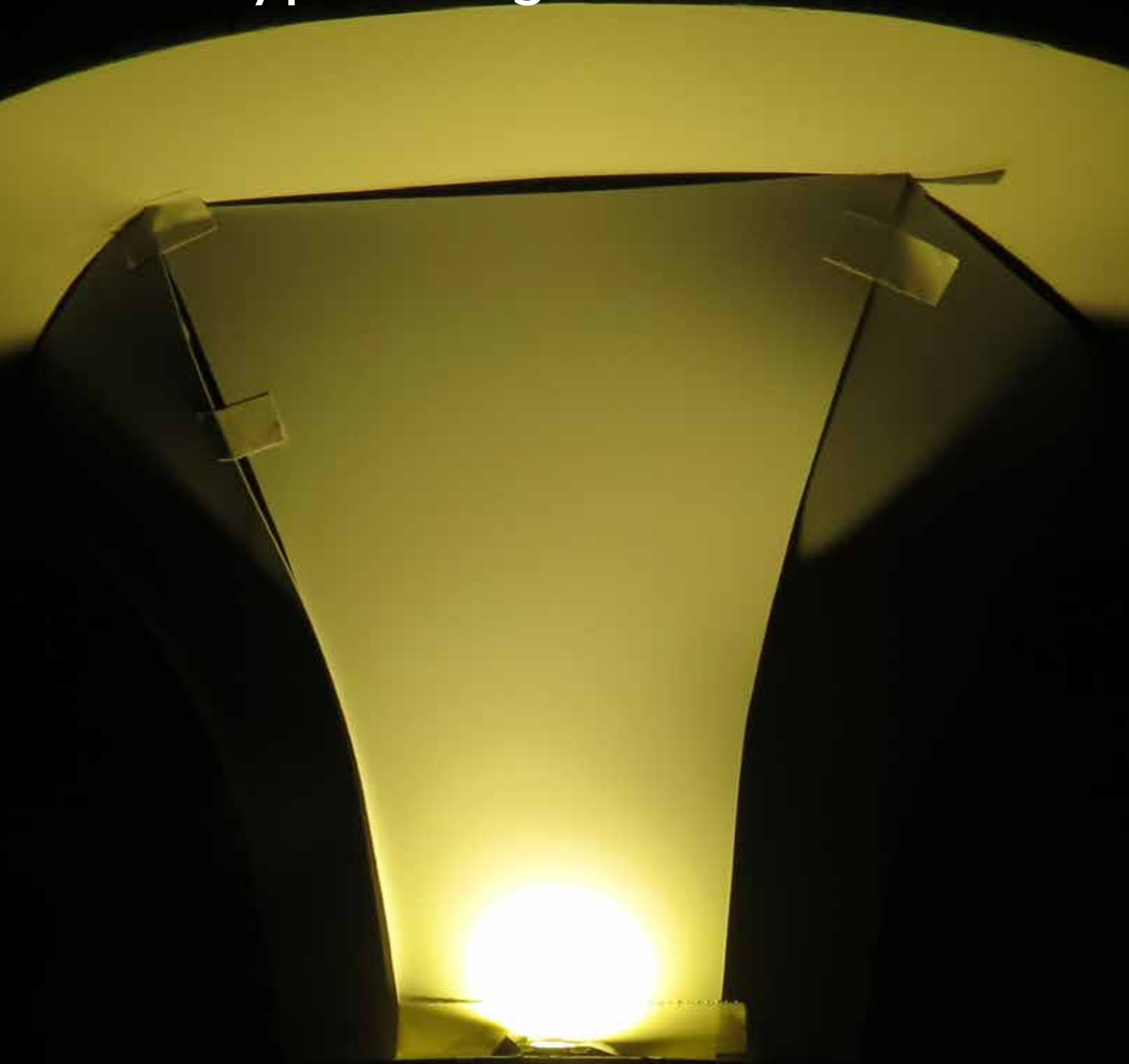



The architectural style is associated with geometric planes and lines. Minimizing the solid volumes produces a style that is visually light, but striking.

The organic style is inspired by natural forms. It is sculptural with complex three dimensional curves to make the light feel grown in place.

The minimal style streamlines all of the components into a single form with simple geometry. Lack of embellishment makes a minimal light pole flexible.

Prototype 1 - Light on a Pole





Prototype one was a “big-ugly” that showed the size, rough form, and rough effect of the Ray system.

The biggest challenge was adapting my existing LED diode arduino wiring to the LED chips, which needed a separate power source. If that high voltage was run through the arduino board, it would fry everything and make it useless. Also potentially my laptop, which was connected to the arduino for programming. That was a scary hour or so.

A similar challenge was not electrocuting myself or shorting out the circuit, because I was using metal alligator clips to connect the heavier wires to the circuit wires. I found out that the entire clip will be electrified, and it is very important to wrap everything in tape to prevent electrocution.

Lots of learning occurring in the making of this, which I will cover on the next page.

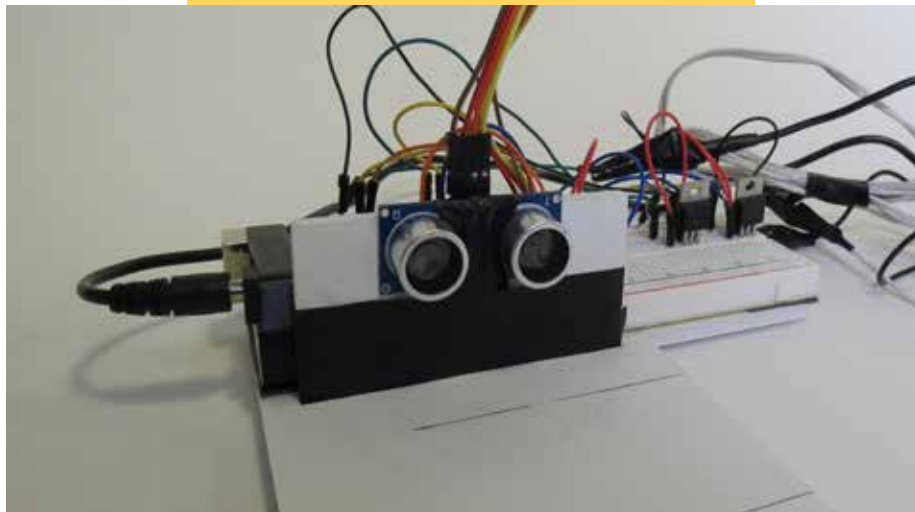


Lessons of Prototype 1

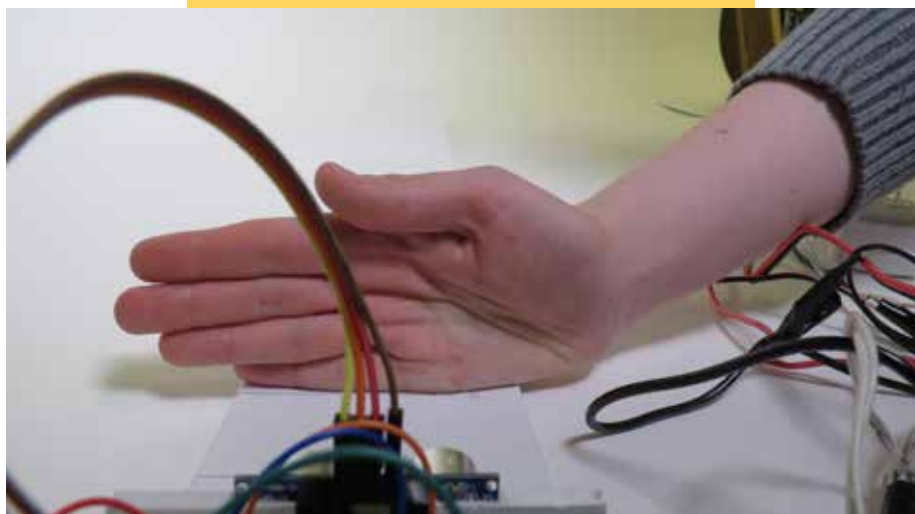
- Heat management is a crucial part of designing an LED luminaire
- Arduino boards do not have enough PWM ports to control as 6 LED chips at once.
- Direct light from these LED chips is very bright and does create glare - so the indirect illumination was a good choice.
- Simplify wire management for assembly and installation
- Use a central axis for alignment of components and account for tolerances



One of two high powered LED chips mounted to a brass plate to distribute the heat



Wire management is a priority for the next model - the circuitry kept getting unplugged when the model moved



Calibrating the sensor with the scale model.

IES and IALD Review

I coordinated with the local Illumination Engineering Society (IES) and International Association of Lighting Designers (IALD) to review and critique my design up to this point.

Feedback

- Light the path in front of the person, not on the person.

Response

- Computer vision data can be analyzed with predictive algorithms to light the path ahead of a person and also to function as wayfinding.

Feedback

- This is similar to a concept that won a lot of awards a few years ago, but it has not been successful due to energy code requirements

Response

- Exterior projects get a higher power allowance in code. Also the premise of the Ray system is that it is dim most of the time - saving more power overall.

Feedback

- This sounds expensive.

Response

- Provide the fixture and controls with different levels of experience to accommodate different price points. Also make other fixture that are not just a pole.



Lillian Knoerzer (IALD Regional Coordinator)

“Placing the light directly on the people may make them feel exposed. If the light was ahead of them it would be a better experience.”



Jared Widmer (IES Former President)

“I have seen proposed lights that work this way, but they fail interior energy code. Exterior public code has a higher energy allowance, so this is a great place to use the concept.”



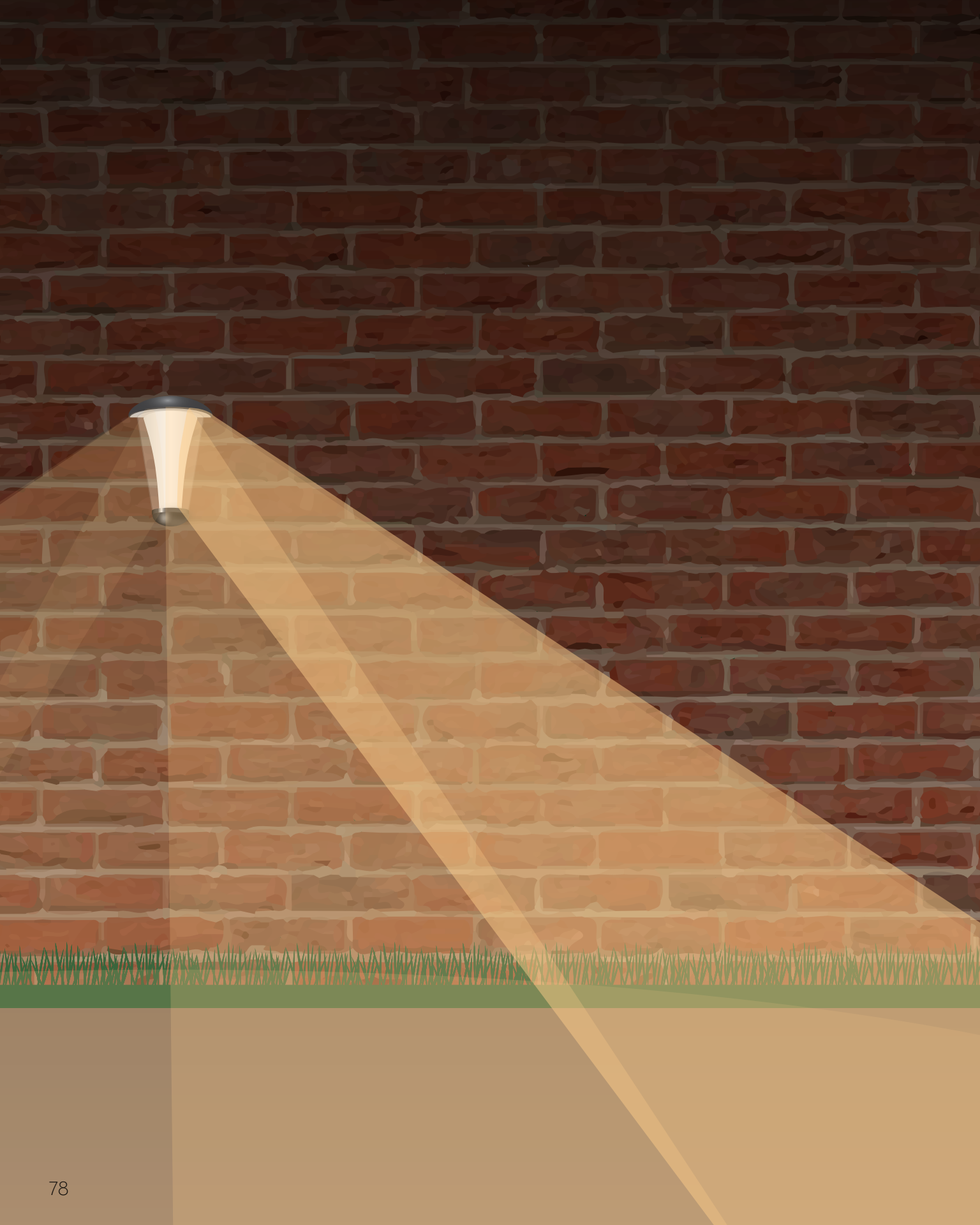
Adam Carangi (IES Manufacturing Rep)

“This sounds really expensive, but if it was available in different sized fixtures with different degrees of control that would reduce the cost and make it more appealing to investors.”

Final Design

The Ray Fixture Family - Modern Collection

- Wall Sconce
 - Post-top Luminaire
 - Bollard
-
- Manufacturing, Assembly, and Installation
 - Final Light Level Interaction
 - Moving Forward



Ray Wall Sconce

The wall sconce is intended for pedestrian spaces and paths that run around buildings. This fixture saves money on the sensors, because it only needs to detect people over 180 degrees instead of all the way around.

The Sconce can be mounted at 8ft - 12ft high, as long as the light source is not visible from the ground to make use of the indirect illumination and avoid glare.



Ray Light Pole

The Light Pole is for large open areas such as parks. The top sensor hub and luminaire can be retrofit to any existing 4in diameter pedestrian pole. The height can range from 10ft to 15ft tall, with a spread of light and pole spaces ratio at 2.5 times the height.





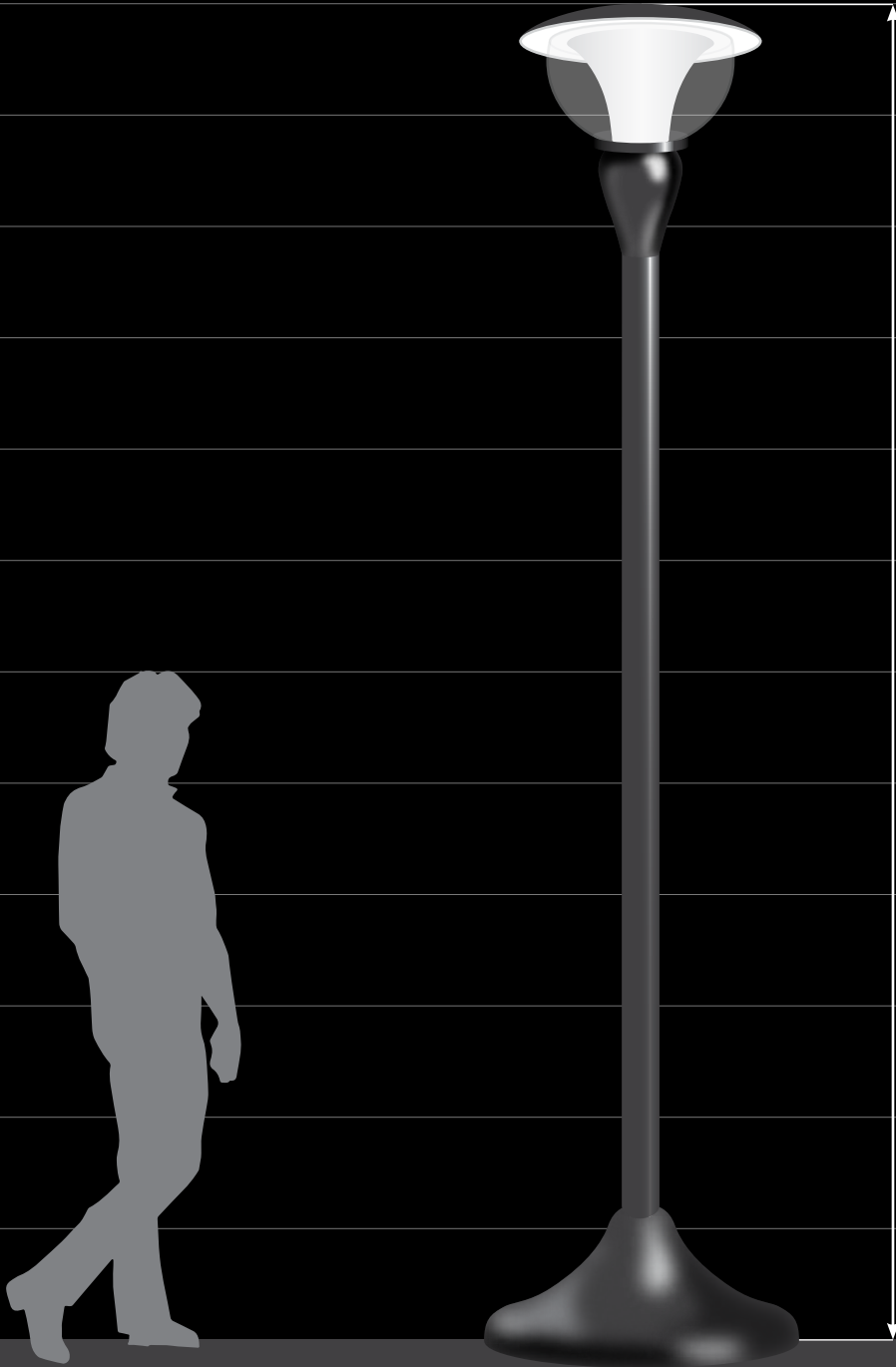


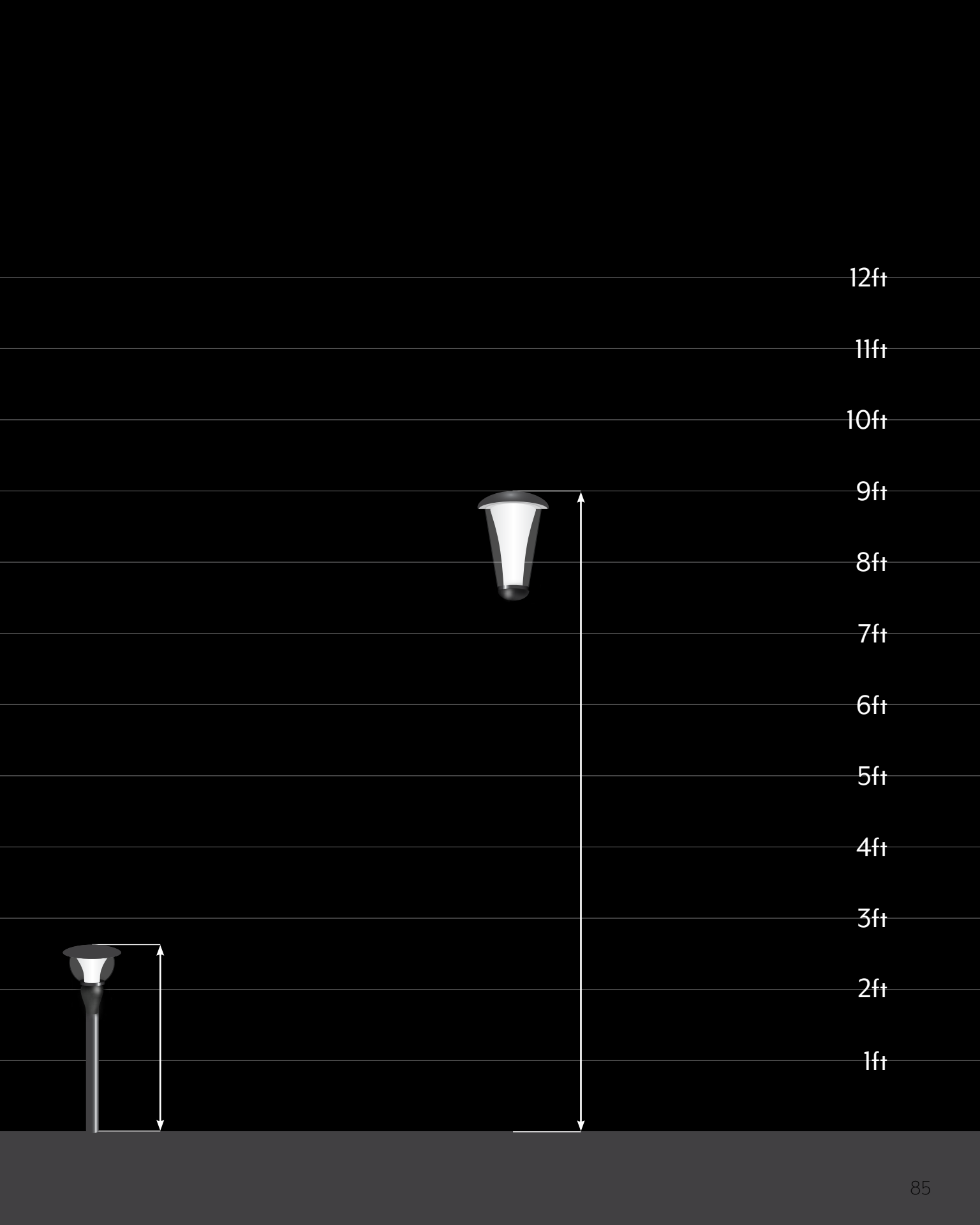
Ray Bollard

The Bollard has the same 360degree sesnor system as the pole, but in a smaller package. This makes it appropriate for tighter spaces such as sidewalks, or anywhere there should be a physicl separation between the pedestrian space and the street.

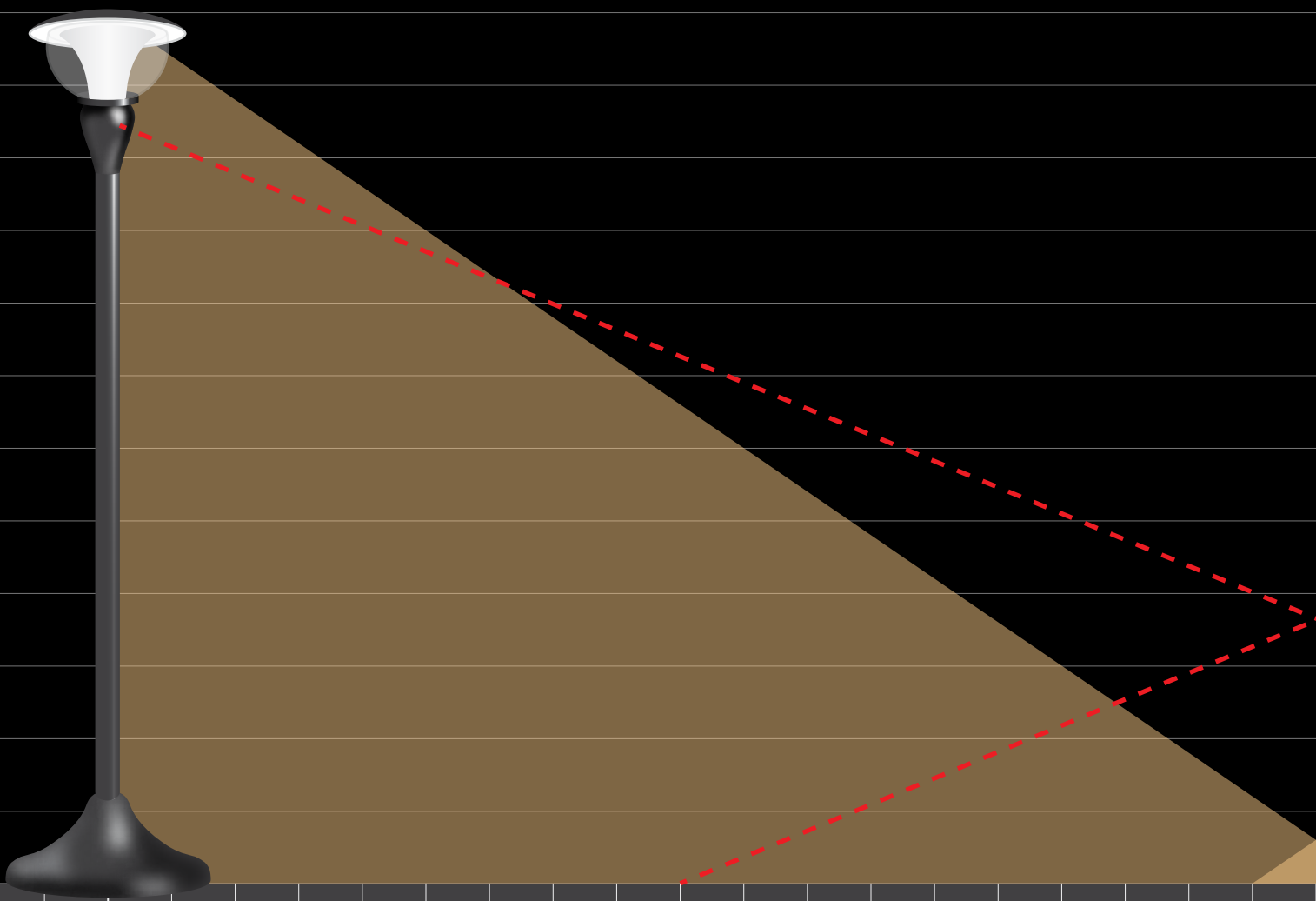


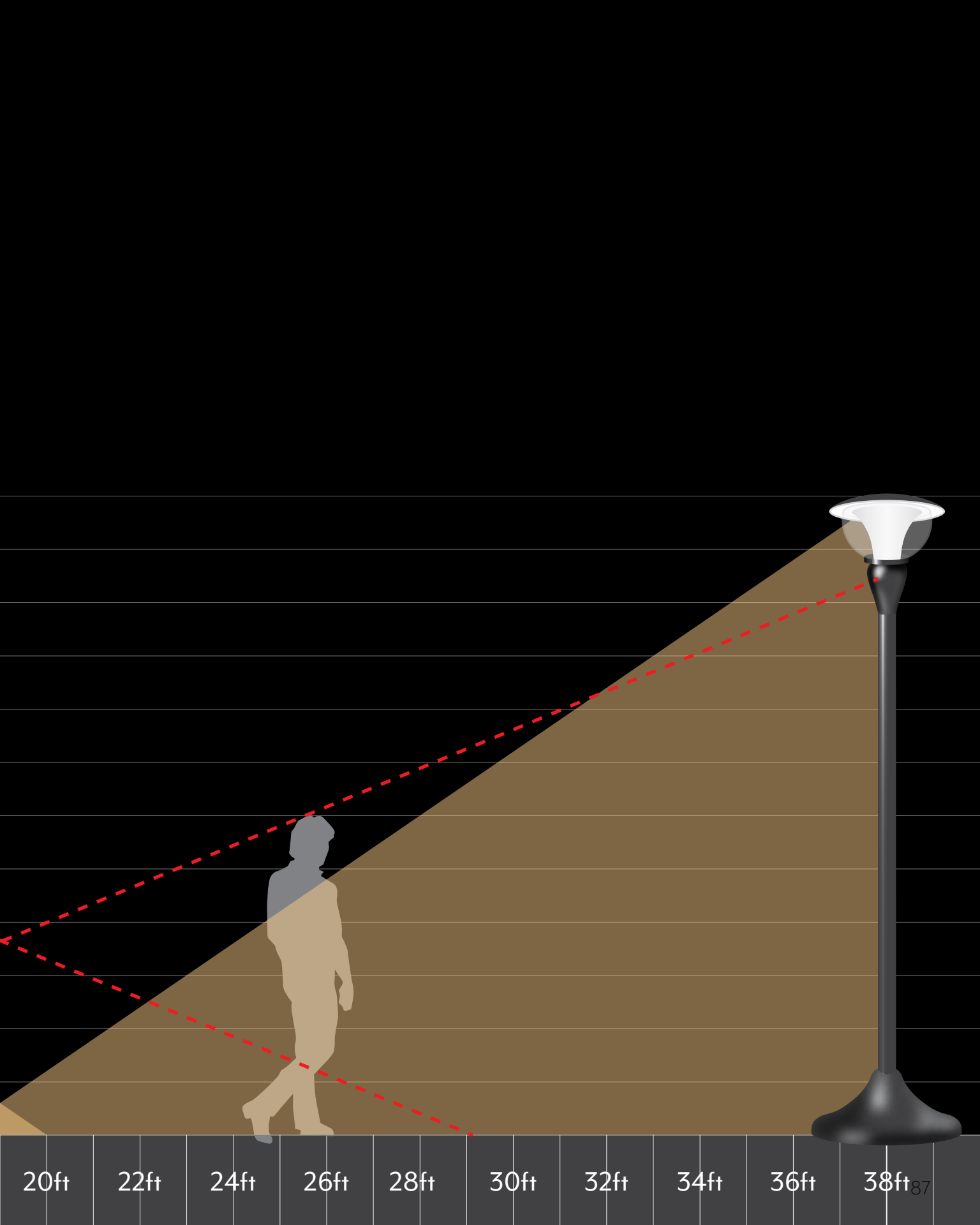
Fixture Mounting Heights



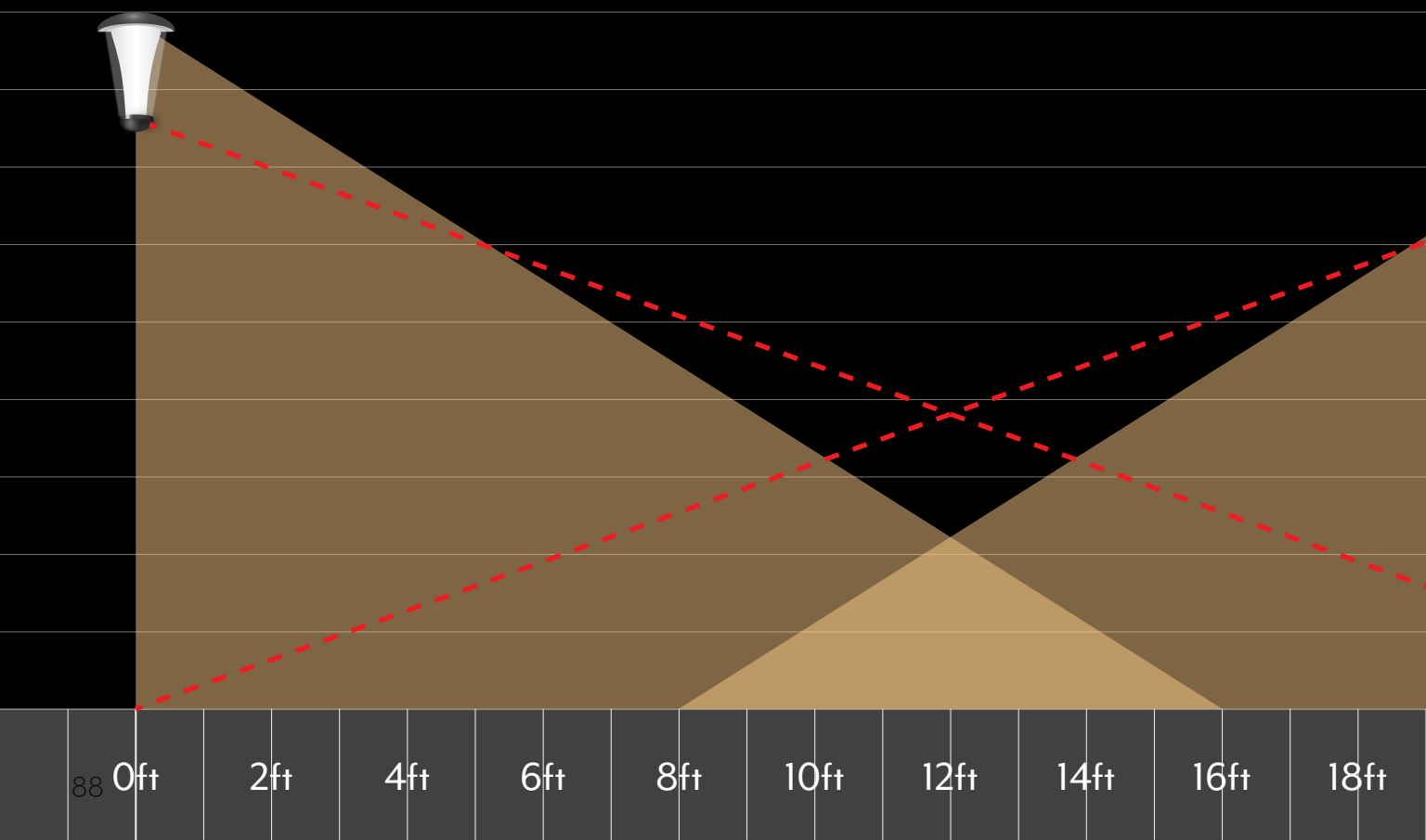


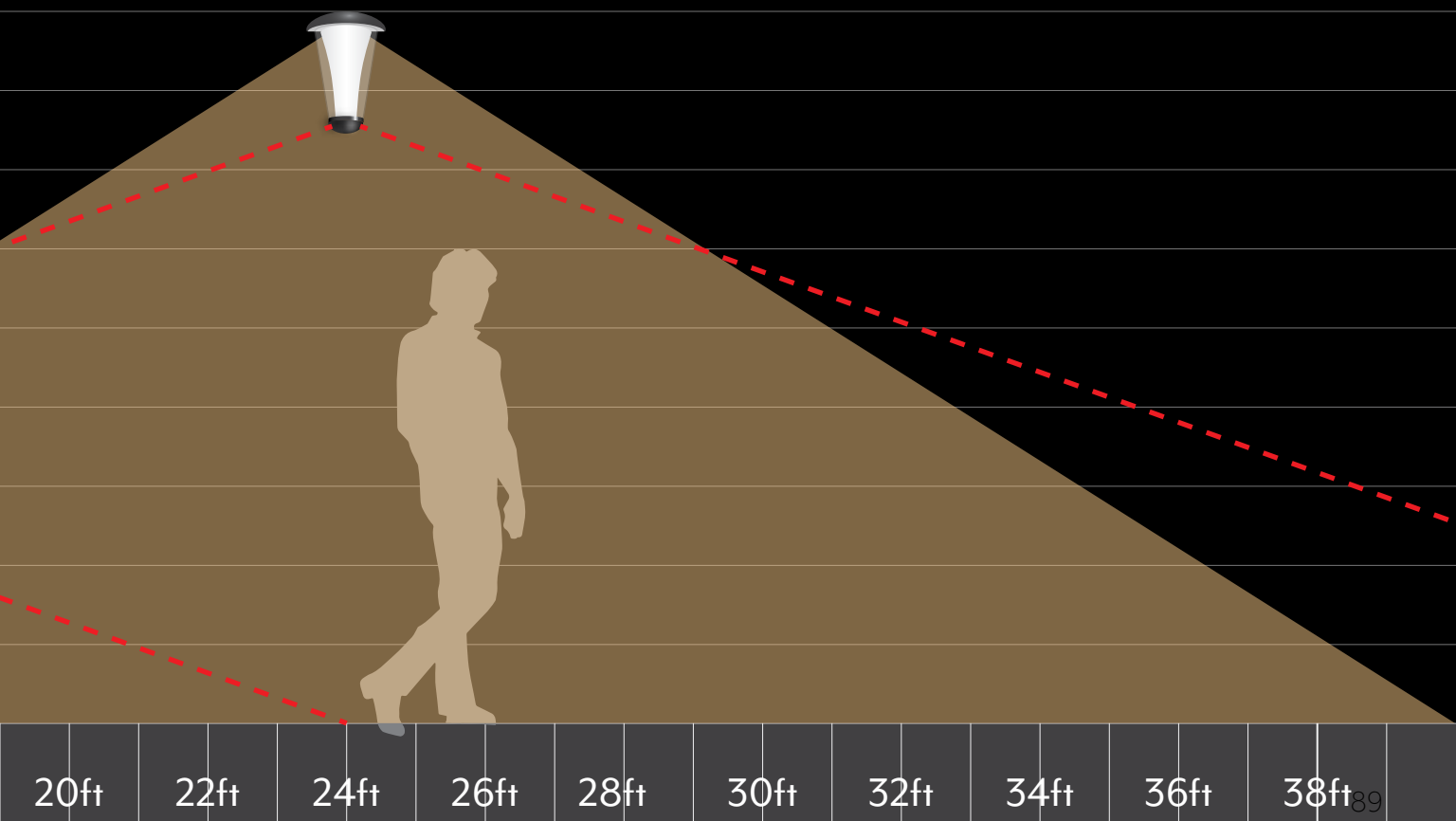
Pole Spacing and Sensors



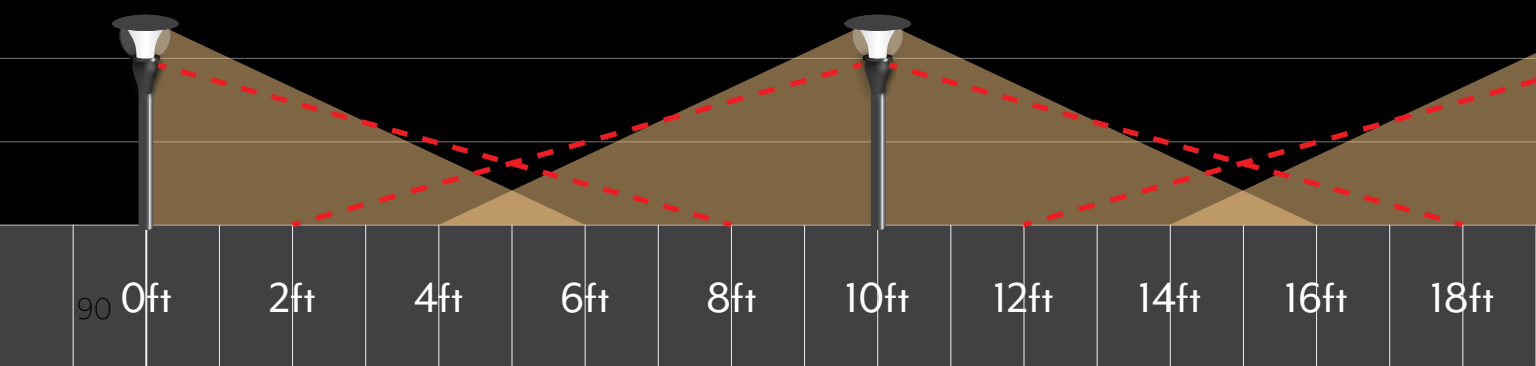


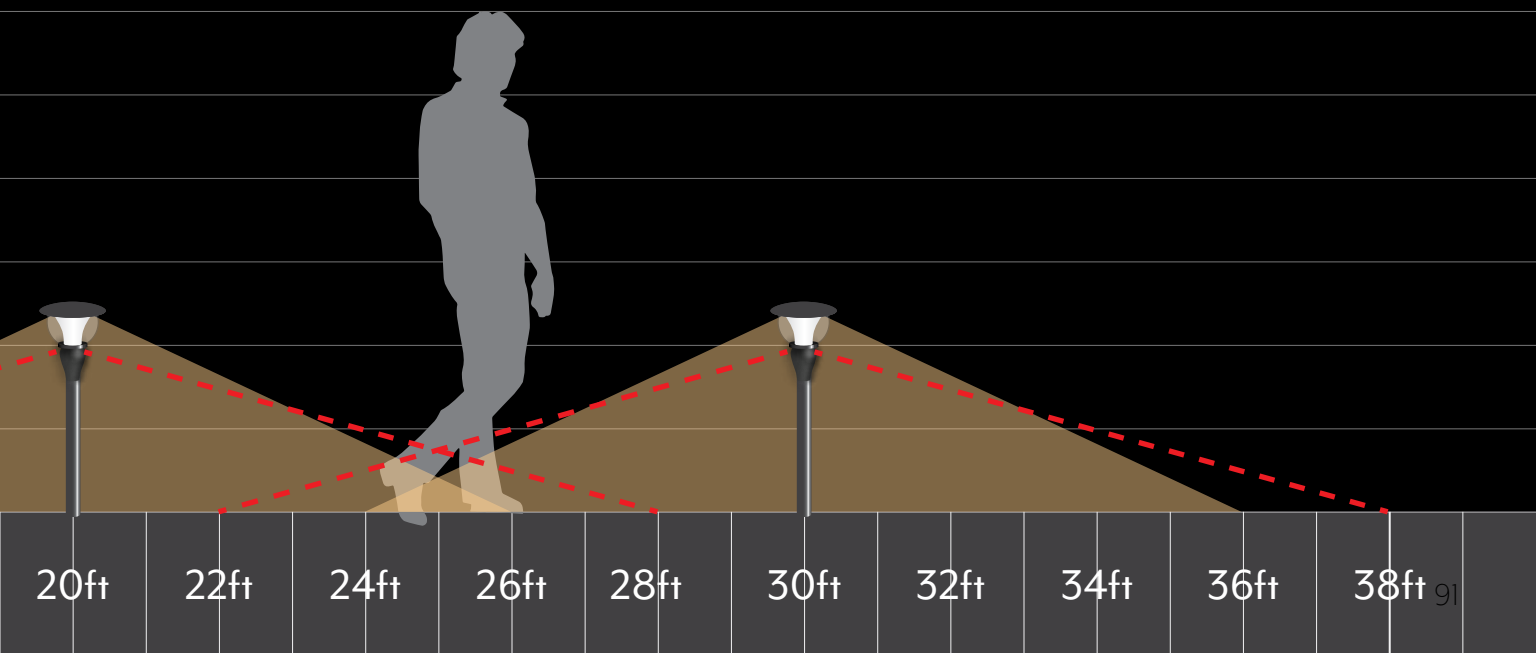
Sconce Spacing and Sensors



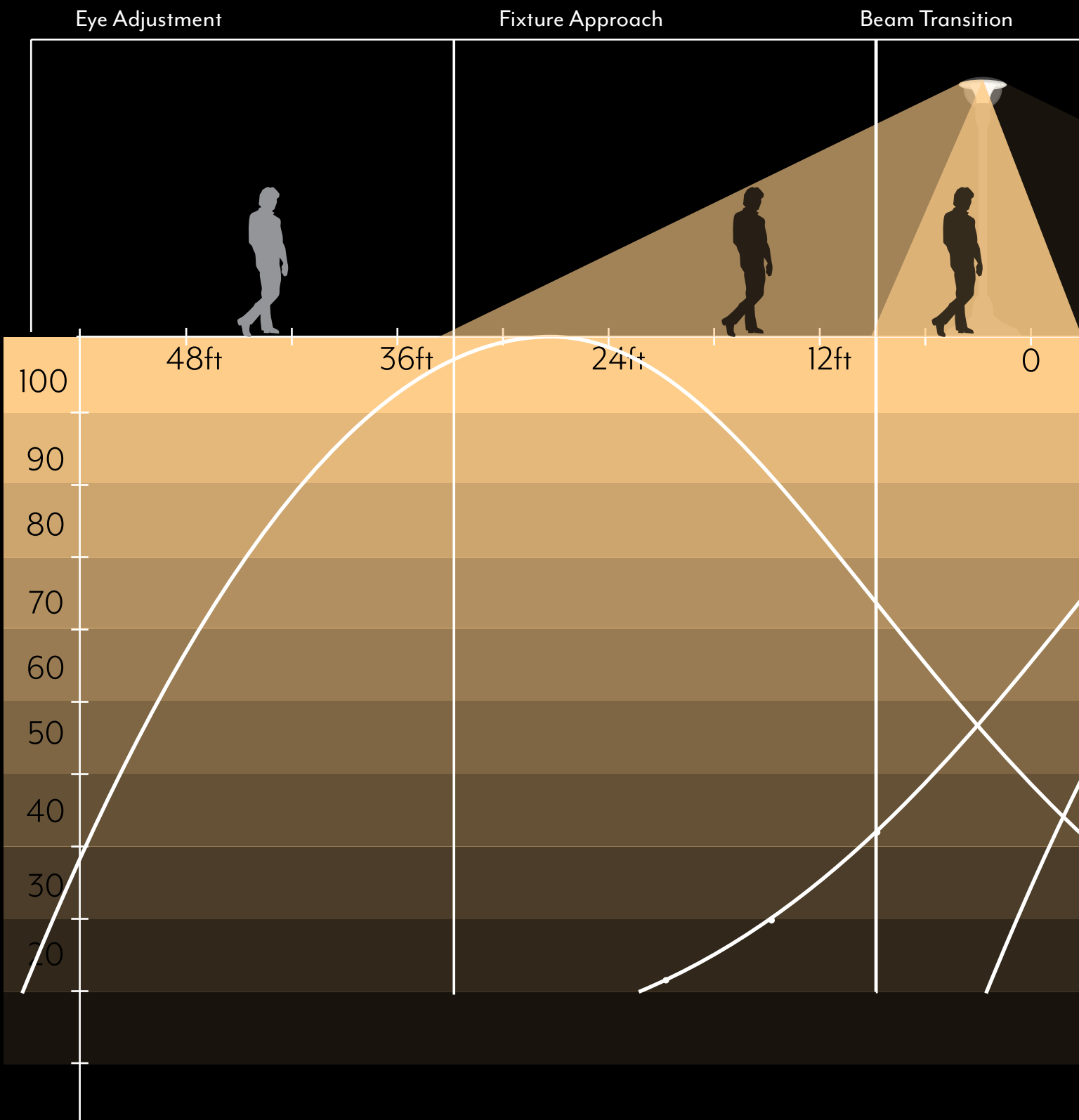


Bollard Spacing and Sensors

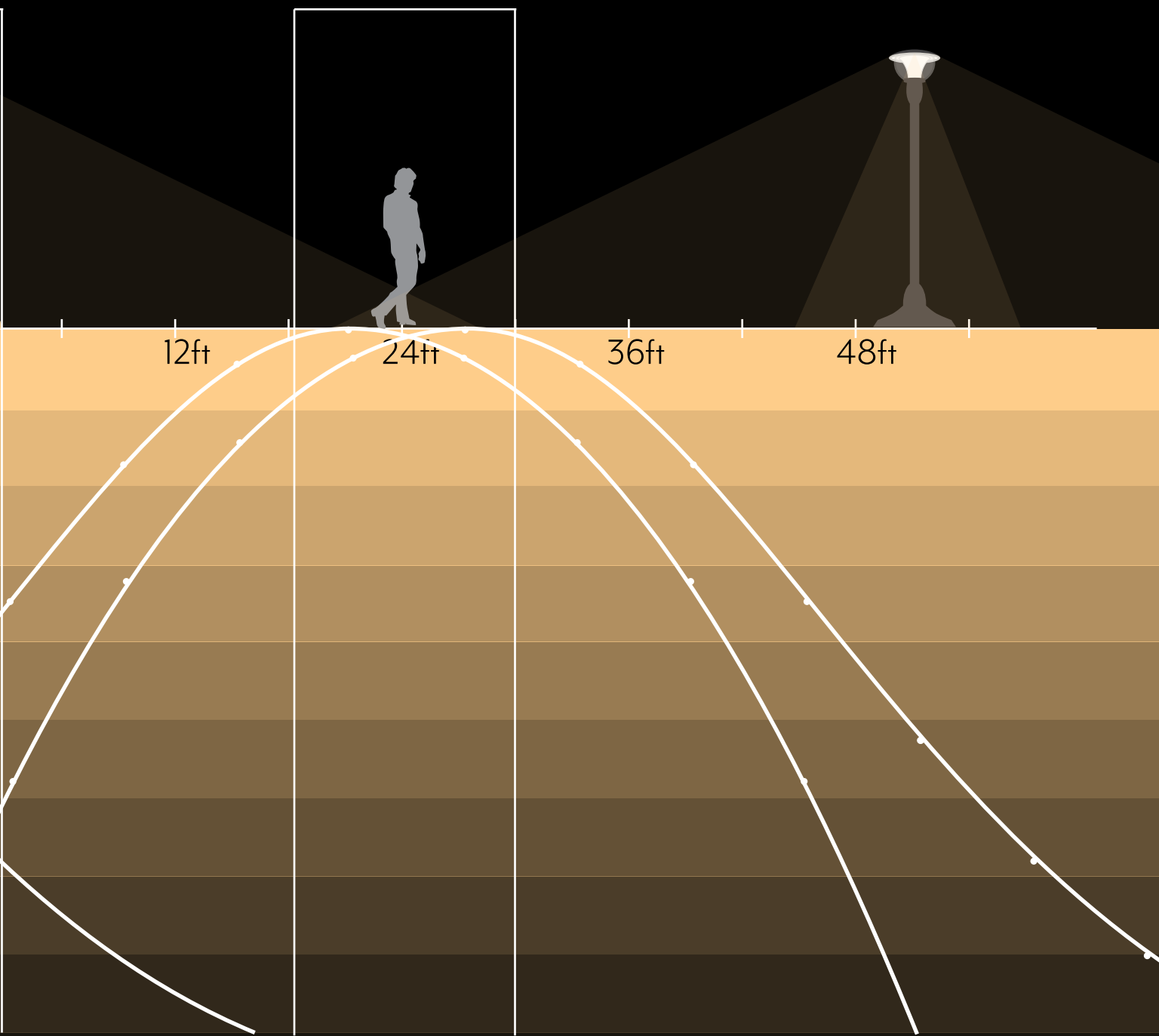




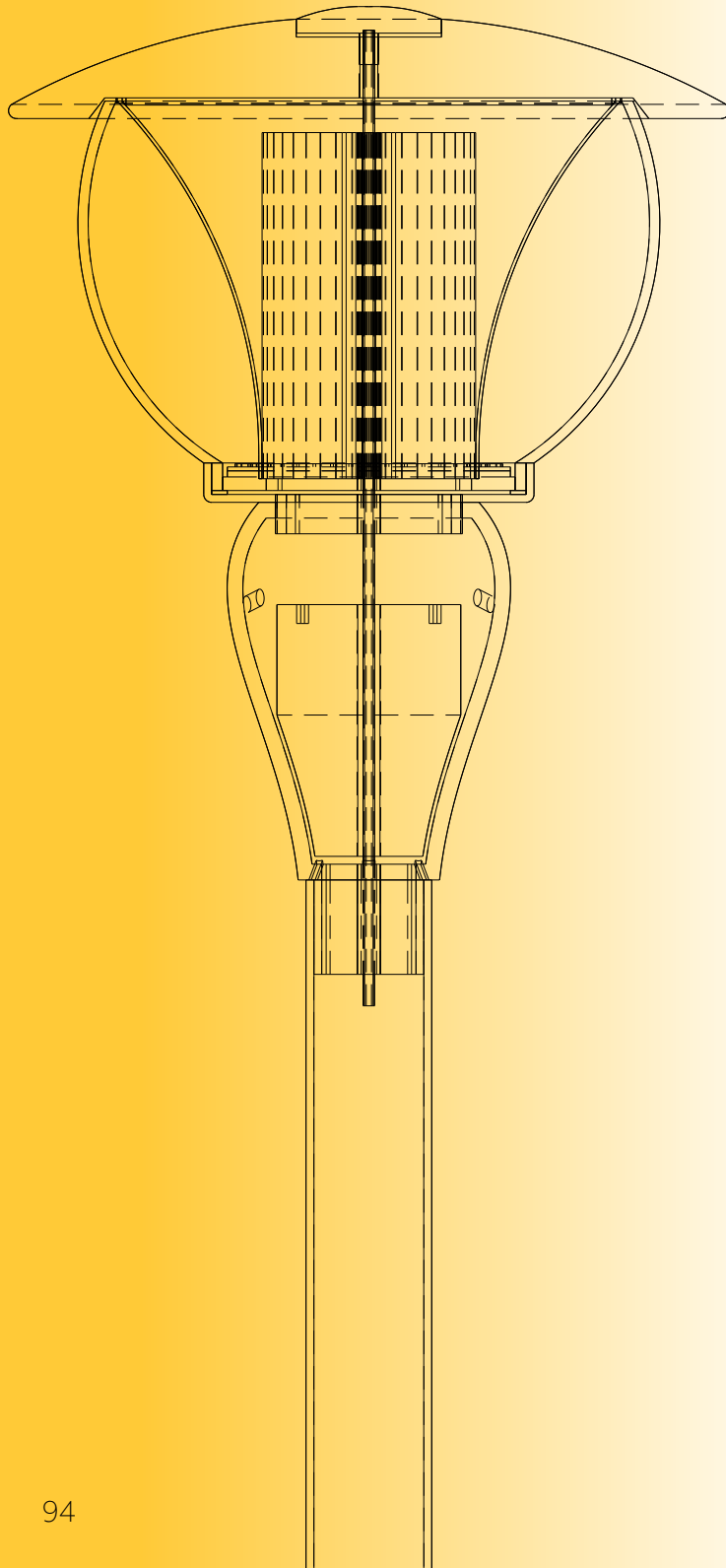
Zones of Illumination



Fixture Transition



Design Details



Top Shield

Finial

Glass Enclosure

Reflector

Aluminum Heat Sink

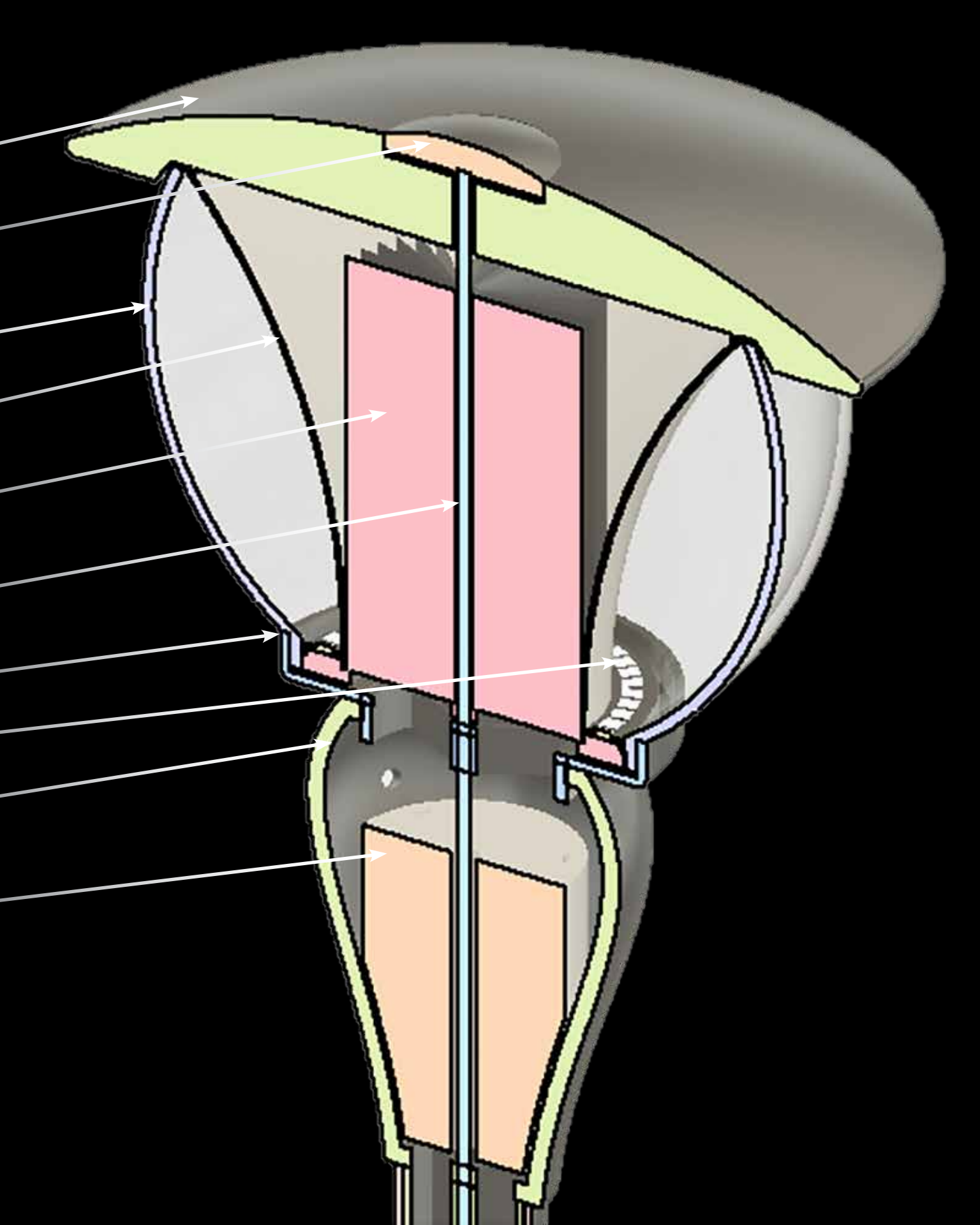
Steel Axis Rod

Luminaire Base

LED Chip Board

Sensor Hub

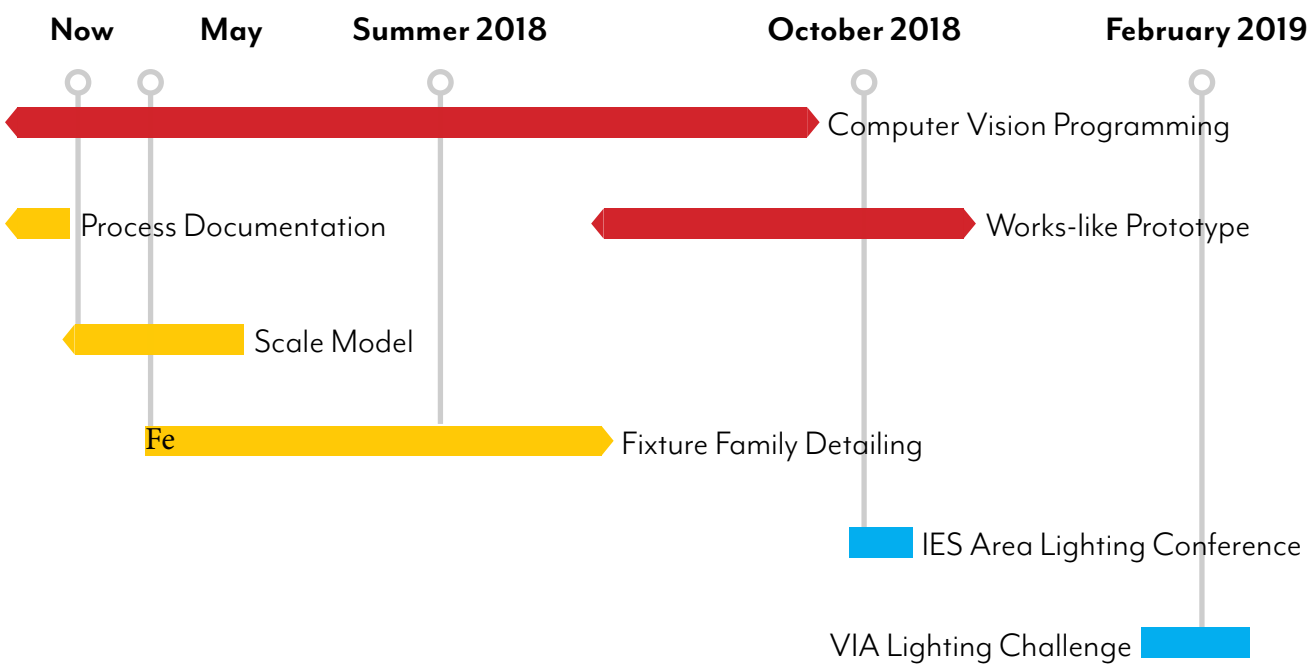
Electronics Block



Moving Forward

The ultimate goal for this project is to fully validate the benefits of dynamic, interactive public lighting. To do this, I would like to partner with a lighting and controls manufacturer to build, program, and install a case study in a pedestrian space. Before I can do that, I need to get a full scale model working that uses the computer vision cameras to detect people. I would also like to develop the other styles of fixture for a more diverse product range.

The Ray lighting system has a lot of potential to change how we think about the future of public lighting. This processes synthesized so many factors of what public lighting affects and is affected by. I think that some of this connections need to be shared with the lighting community, so I am hoping to attend the IES Area Lighting Conference in October 2018, as well as speak on the potential benefits of smart lighting infrastructure as part of the Via Lighting Challenge in Berlin in February 2019.








Ray

Smarter Public Lighting



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